Like a drug: A mixed-methods anthropological interrogation of swaddling.

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"Like a drug": A mixed-methods anthropological interrogation of swaddling.

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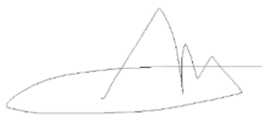
Declaration and statement of copyright

This thesis is the PhD project of Allison Dixley in the Department of Anthropology at Durham University, funded by The North East Doctoral Training Centre (NEDTC) (Grant number ES/J500082/1). My partner for the project is UNICEF UK BabyFriendly Initiative, the leading UK NGO involved in promoting infant feeding support and health professional training. I declare that this thesis is my (Allison Dixley) own work and that, to the best of my knowledge and belief, it contains no material previously published or written by another person, except where due acknowledgement has been made in the text. I confirm that no part of the material presented in this thesis has previously been submitted by me or any other person for a degree in this or any other institution.

Signed:



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Abstract

Swaddling is a global infant-care practice in which a piece of material is wrapped firmly around an infant's body, thought to pacify the infant. This thesis aimed to understand the practice of swaddling from a holistic perspective with a view to addressing several knowledge deficits.

Methods

Responding to calls for a more holistic approach to the study of infant sleep (McKenna, Ball et al. 2007), the thesis conducted an integrated anthropological interrogation encompassing evolutionary, historical, ethnographic, and biosocial perspectives. The thesis was composed of five components: 1. four-part synthesis of the swaddling-related literature. 2. systematic review of video-based methodology in infant sleep research. 3. lab-based study investigating the impact of swaddling upon infant physiologic and behavioural states. 4. Development and evaluation of novel method of calibrating swaddle tightness. 5. survey of health professionals' swaddling-related knowledge and opinions.

Results

Firstly, the literature review positioned swaddling as a universal practice implemented in culturally specific ways. It revealed that infant needs and parental responses are dynamic and interdependent. Next, the systematic review provided in-depth evidence highlighting video as a significant resource for infant sleep researchers albeit with methodological 'trade-offs' in validity. The findings of the lab project indicated that naïve breastfed infants' respond to swaddling in a way that deviates from that previously seen in formula fed subjects. Namely, the naïve breastfed infants did not demonstrate alterations in sleep length when swaddled but experienced an extension of active sleep. Outcomes of the swaddle tightness project indicated the device had a high degree of reliability under experimental conditions. Finally, respondents to the survey thought newborns most appropriate for swaddling, with significant preference given towards non-routine swaddling and the 'hands out' configuration.

Conclusion

The thesis unveiled a range of ethical, methodological, and ontological tensions, and highlighted gaps in knowledge pertaining to swaddling.

Acknowledgements

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In memory of Neil Dixley (1969-2019),

Loving father of Amy and Neil Jr.

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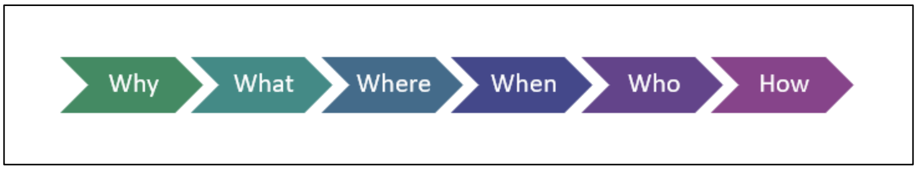
Chapter 1. Introduction

> *"It works like a drug, alcohol or poppy seeds: It switches off the baby" (Frenken 2011)(p90)*

Swaddling is a global infant-care practice in which a piece of material is wrapped firmly around an infant's body to restrain limb movement. The procedure is thought to pacify the infant and to transform them into a soft, compact, portable entity, not visually dissimilar to a burrito (Oden, Powell et al. 2012), a loaf of bread (Calvert 1998) or a small log of wood (Benedict 1949). Recently, the practice has experienced a resurgence in popularity in so-called WEIRD societies (western, educated, industrialized, rich and democratic) (Henrich, Heine et al. 2010), as a tool to encourage infant sleep, 'like a drug'. Sleep is an essential part of life, and scholars highlight "the Western cultural obsession with infant sleep" (Rudzik and Ball 2021)(p2), which has generated a profitable 'sleep industry' (Ball 2020). In a recent survey of 869 Australian mothers 77.2% said they usually swaddle their infants to sleep (Cunningham, Vally et al. 2018). This thesis aims to understand the practice of swaddling from a holistic perspective via reviews of the previous literature and primary research.

The present chapter will give a high-level overview of the thesis, through answering the fundamental questions: Why? What? Where? When? Who? How? I will begin by outlining the background of the thesis (Why). Then, I will detail the scope of the topics to be investigated, and the general aims and objectives of the research (What). Next, I will briefly explain the location and setting of the study (Where) and outline the contextual nature of the time period (When). After this I specify the subjects of my work and the populations from which they were selected (Who). This discussion is followed by an explanation of the research procedure, including a description of the research design (How).

Figure 1 Chapter framework.



Why

The contemporary Western swaddling renaissance can perhaps be attributed to a common belief that swaddled infants cry less (Caiola 2007, Karp 2007, Akhnikh, Engelberts et al. 2014). In the 2006 publication of their newsletter, breastfeeding organisation La Leche League (Dallas US) referred to swaddling as a "tried and true" soothing technique and likened it to the confines of the womb (Dunnewold 2006). Yet, as swaddling has surged in popularity, so have concerns and controversies. The degree to which swaddling may be harmful has emerged as one of utmost import, given the widespread prevalence of the practice.

Contemporary swaddle technique may involve a traditional wrap, made from either cotton, muslin or merino wool, or a specialised commercial swaddle product. These include swaddle pods that zip up, triangular 'T' or 'Y' shape breathable fabrics which may include velcro or poppers, swaddle bags that include 'wings' that fold around the baby's body and arms, or a pouch that allows the baby's hips and legs to move naturally. When parents follow recommended guidelines and swaddle for every sleep (The Lullaby Trust 2020), their infants typically spend 70% of their time under motor restraint (So, Adamson et al. 2007).

As well as being used in domestic contexts, swaddling is applied in numerous medical settings. Neonatal clinicians use the intervention as a method of pain relief, to promote sleep, and as a means of motor restraint for medical procedures (Dezhdar, Jahanpour et al. 2016). A shift towards maternal reliance on clinical advice - seen as inherently 'authoritative' – lessened mothers' use of traditional advice networks, such as family and friends. In one American study, 61% of parents of young infants preferred to obtain swaddling advice from health professionals over any other source (Oden, Powell et al. 2012). Determining professionals' understandings of swaddling is therefore important in the construction and dissemination of guidelines.

However, due to uncertainty as to beneficial and deleterious outcomes, professional and public bodies such as the American Academy of Paediatrics, Canadian Pediatric Society, UNICEF UK, and the NHS, refrain from taking an official stance on swaddling (Kennedy and Glassy 2013). In 2019 the Lullaby Trust (UK SIDS prevention and bereavement support charity) cited swaddling at the top of their list of factors in need of further research (The Lullaby Trust 2019). The intervention has been shown to encourage longer and deeper infant sleep (Franco, Scaillet et al. 2004, Meyer and Erler 2011) with a noted reduction in motor activity, fewer startles, and lower heart rate variability (Lipton, Steinschneider et al. 1965). Worryingly, it has been associated with dislocation of the hip (Akman, Korkmaz et al. 2007), acute respiratory infections and overheating (Yurdakok, Yavuz et al. 1990).

Of further contention are infant feeding outcomes. Concerns sparked by low breastfeeding rates in Westernised societies have driven a shift in policy thinking and increased public discourse on the topic (Unicef 2020). Of central import is the association between feeding method and sleep and arousal (Horne, Parslow et al. 2004, Quillin and Glenn 2004, McKenna and McDade 2005). Breastfed infants are known to wake more frequently and develop consolidated sleep later than their formula fed peers (Elias, Nicolson et al. 1986). Yet the effect of swaddling upon feeding, and breastfeeding in particular, remains unclear. In a similar vein, no studies to date, have explored the impact of swaddling upon maternal-infant sleep interaction and maternal-infant sleep orientation, despite these factors being associated with breastfeeding outcomes (McKenna 2004, Ball, Ward-Platt et al. 2006, Ball and Klingaman 2007, de Graag, Cox et al. 2012, Gross, Mendelsohn et al. 2016) and risk of Sudden Infant Death Syndrome (SIDS) (Mosko, McKenna et al. 1993, McKenna and McDade 2005).

SIDS refers to the sudden and unexplained death of an apparently healthy infant younger than 1 year old. Some studies have linked swaddling to an increase in SIDS risk (Blair, Sidebotham et al. 2009), yet earlier studies suggested that swaddled infants had decreased risk for SIDS, even over and above unswaddled supine sleeping infants (Ponsonby, Dwyer et al. 1993, Wilson, Taylor et al. 1994). Physiological evidence suggests that suppression of arousal mechanisms is an important component of this syndrome (Byard and Krous 2001). Infants who subsequently become SIDS victims have been shown to sleep for longer periods, wake less often and display marked difficulty in arousing when compared to healthy infants (Einspieler, Widder et al. 1988, Harkness and Super 2006, Harper and Kinney 2010). In 2016 the American Academy of Pediatrics (AAP) Task Force on SIDS noted a knowledge deficit regarding epidemiological evidence, i.e. "epidemiological data directly linking swaddling with SIDS or problems with arousability are lacking" (Goodstein, Hauck et al. 2016) (p160). A 2017 systematic review built upon the concern of the AAP, concluding that "research about the impact of swaddling on arousability and vital signs is unclear, and further research is needed" (Nelson 2017)(p218). Identifying modifiable factors that impact upon infant sleep and arousability is therefore a public health imperative. As SIDS is only known in humans (Kinney, Rognum et al. 2012), it is plausible that a human intervention, such as swaddling, may increase risk.

A largely neglected but important area in the study of infant sleep and arousal is the interaction between interventions and sleep states. As recently as 2015, a systematic review found that swaddling significantly reduced changes in sleep state and promoted low-responsive sleep (Dixley 2015). In this respect, the intervention is mismatched with the way human sleep architecture has evolved. By encouraging quiet sleep at a time in ontogeny when arousal mechanisms are underdeveloped, swaddling may handicap an infant's ability to handle a regulatory crisis, such as prolonged apnoea. Such theories suggest that the physiological effect of swaddling may differ according to sleep state, a research gap identified in two systematic reviews (van Sleuwen, Engelberts et al. 2007, Dixley 2015).

Despite several clinical studies exploring these physiological responses, a clear consensus has not been achieved. Perhaps a different approach is needed, one that considers the holistic character of the human condition. The scientific study of human behaviour, human biology, cultures and societies, in both the present and past – Anthropology - can offer unique insight into swaddling. Inspired by anthropological critiques of clinical and populist conceptualisations of infant sleep (Ball, Tomori et al. 2019), this thesis asks: Does swaddling reflect cultural and historical beliefs pertaining to personhood, humanity and the concept of infancy? In what ways does swaddling replicate or reinforce the evolutionary norms of infancy, and does this matter? Are swaddled infants really being 'soothed', or does swaddling cause newborns to shut down?

What

In 2007 McKenna and colleagues called for a more holistic, integrative approach to the study of infant sleep (McKenna, Ball et al. 2007). Well over a decade later, Gordon et al echoed this sentiment, urging for cross-fertilization in infant sleep research (Gordon, Rowe et al. 2015). Contemporary scholars continue to advocate for multi-disciplinary, no-holds-barred, collaborative infant sleep enquiry (McKenna and Gettler 2017, Mileva-Seitz, Bakermans-Kranenburg et al. 2017). Some have suggested this emerging field should even extend beyond sleep studies, to include "other controversial parenting practices and parent-child interactions" (Mileva-Seitz, Bakermans-Kranenburg et al. 2017)(p16). They suggest the creation of a new field of study known as 'psycho-anthro-pediatrics'. This exciting prospect aims to unify the psychological, anthropological, and medical sciences of infant research. My work aims to contribute to the development of this field. Yet despite loud voices, their cries have fallen upon many deaf ears.

This thesis gives credence to the vision of McKenna and colleagues. It was inspired by their hypothesis that solitary sleeping removes the infant from the regulatory effects of its mother's body and places it in a more physiologically challenging sleep environment (McKenna 1996). My work aims to build upon this hypothesis by likening the dynamics of solitary sleeping with those procured through swaddling. The ultimate result is theorised as the biobehavioural decoupling of mother and infant. The aim of the thesis is to enhance understanding of the infant and maternal-level consequences of swaddling. In pursuit of this aim, the thesis adopts an integrative and holistic approach, typical of anthropological enquiry.

My truth-seeking marathon begins with a thorough four-part synthesis of the literature exploring what could be the precise mechanisms involved in the production of swaddle outcomes? Given that evolutionary processes play important roles in biobehaviour and in the development and maintenance of infant and maternal health, I begin with a review of the evolutionary literature (Chapter 2). Here I consider swaddling through the lens of evolutionary adaptation. Using the context of our ancestral environments, I offer insights into the intersection between adaptive and maladaptive maternal-infant behaviours pertaining to swaddling. Next, I consider the historical prevalence of swaddling, asking what evidence is there to position swaddling as a socialization and humanization strategy? The answer to this question can be found as I explore the social and cultural dimensions of infancy. In this sociohistorical review (Chapter 3) I identify and investigate the ways in which infants' bodies have been conceptualized, as reflected in swaddling practices. This is followed by a thorough multi-part review of the biobehavioural literature, where I investigate the interplay between swaddling as an environmental intervention and behavioural and biological factors (Chapter 4). The literature review section of the thesis ends with an inquiry into how infant bodies, in conjunction with swaddling, are negotiated within the health care system. This clinical review (Chapter 5) will seek to answer the question: To what degree is swaddling health-promoting or health-harming? Before embarking on my applied study of swaddling, I prepare with a systematic review. Within the past decade, the issue of the most appropriate way to assess sleep in research settings has been elevated to the forefront of discourse (Galland, Meredith-Jones et al. 2016, Rudzik, Robinson-Smith et al. 2018, Tikotzky and Volkovich 2019, Del-Ponte, Xavier et al. 2020, Quante, Hong et al. 2020). As the cost of video equipment and production has declined, sleep research has seen a surge in the popularity of video-based methodology (Jewitt 2012). In response, I conduct the first systematic review to critically assess video as an investigative tool in infant sleep enquiry (Chapter 6). The thesis now turns to the generation of primary data. Using the facilities of the Durham Infancy & Sleep Centre sleep laboratory I investigate the impact of swaddling upon infant physiologic and behavioural states (Chapter 7). Effects on sleep states, feeding, and maternal interaction, are recorded, coded and analysed. Thereafter, Chapter 8 addresses a conundrum I encountered in my lab research. The methodology gap, espoused over a decade ago, maintains that "caretakers need some simple method to determine pressure in swaddled infants" (Thach 2009)(p461). After investigating how the relative tightness of a swaddle impacts many aspects of infant functioning, both physical and mental, I introduce an innovative pressure sensor device. In that chapter I detail how I used the device and tested its ability to operationalise and calibrate swaddle tightness. Thereafter, just as the literature review ended with a clinical component, my applied research concludes similarly. Indeed, the clinical environment and those that cultivate it, are important factors in the performance of swaddling. Therefore, Chapter 9 explores the swaddling-related knowledge and opinions of health professionals. Using survey methodology, I investigate whether swaddling opinion differs according to occupation type and occupation length and then outline the clinical implications of my findings.

Where

When performing an integrated anthropological study, it is important to acknowledge sociocultural context. Whilst the literature review and systematic review explore data from all inhabited global continents, practicality restricts the rest of the thesis to the WEIRD society of the United Kingdom (Henrich, Heine et al. 2010). The survey project builds upon an international knowledge-base of professionals' swaddling views, by providing the first UK-based investigation of this topic. The sensor project and the sleep study were both performed within North-East England.

Figure 2 Map of the British Isles (UK)

When

This thesis was conducted during the era of the early 21st century (2015-2021), a time when swaddling was experiencing a Western resurgence. In 2013, shortly before I commenced this thesis, UK heir to the throne, Prince William and his wife the Duchess of Cambridge, left St. Mary's Hospital London with their newborn son, Prince George Alexander Lewis, swaddled in a car seat with incorrect restraints. Although this prompted media outcry, the event led to a surge in demand for swaddle blankets. During this era the United Kingdom was characterised by numerous political and social tensions including several changes in Prime Minister and the advent of a global pandemic. The year 2016 was dominated by the UK's vote to leave the European Union and the subsequent political fallout. These events were followed by the 2017

Manchester Arena terrorist bombing, and later by a general election in 2019. Thereafter, the COVID-19 pandemic dominated the political and social agenda until Summer 2021. Regarding the thesis, I wrote the protocol and underwent a progression viva in 2015; Data for the lab and sensor components of the thesis were collected 2016-2019, during which time I undertook a period of maternity leave and later completed an academic secondment within UK Government (Dixley, Boughey et al. 2020); Data for the survey were collected in 2019; Finally, analysis and writing-up was undertaken from 2019 through to 2021.

Who

Researchers and clinical practitioners have been criticised for their tendency to assess either the behaviours of the infant or behaviours of the mother (Tully, Stuebe et al. 2017). That approach overlooks the physiologically and psychologically interconnected nature of the mother-infant dyad (Tully and Ball 2018). In contrast, by adopting a holistic, psychoanthropediatric approach, this thesis will position mothers and infants as one co-related package wherever possible, giving credence to the anthropological observation that "it is the dyad, and not the infant, that constitutes the major unit for study and analysis" (McKenna 2004)(p513).

In the systematic and literature reviews I adopt an understanding of 'infant' as outlined by the World Health Organisation (2014): 'a child younger than one year of age.' This includes premature infants, who are regular candidates for swaddling. For these projects I adopt a global perspective, including cultures that swaddle for longer than Western benchmarks. In contrast, my empirical work focuses upon dyads situated in the United Kingdom.

Although there has been a recent influx in the number of empirical sleep studies employing breastfeeding dyads (e.g., Bailey, Tawia et al. 2020, Abdul Jafar, Tham et al. 2021, Gordon, Mason et al. 2021, Ozturk, Boran et al. 2021, Zandona, Matos et al. 2021), formula fed infants continue to be function as the primary participants of infant sleep research (Barry 2021). Conversely, my lab project was restricted to breastfed infants, the species-specific norm. Inclusion criteria in both the lab and sensor projects required that infant participants were no older than 4 months of age at the time of the experiments, and in good health (understood as the absence of disease or disability). At the time of data collection, 4 months was the commonly cited age point at which infants begin to physically roll to their front (McDonnell and Moon 2014, Moller, de Vente et al. 2019) - a recognised risk factor for SIDS in the West[1]. My survey of 196 health professionals' is performed against this cultural backdrop. Comprising mostly midwives, health visitors and lactation consultants, the survey is designed with Western clinical assumptions in mind.

[1] Since data collection, the American Academy of Paediatricians have redefined rolling age as > 3 months American Academy of Pediatrics. (2020). "Movement Milestones: Birth to 3 Months." Retrieved 30/08/2021, from https://www.healthychildren.org/English/ages-stages/baby/Pages/Movement-Birth-to-Three-Months.aspx.

How

The complex nature of 'the swaddle' topic demands sophisticated, evidence-based research. Functioning as both a verb and a noun, the swaddle straddles disciplines and methodologies, with problems and controversies not always well-defined nor universally accepted. This topic also presents the challenge of addressing the needs of a diverse range of audiences, from the public to policymakers. To contribute to the canon of shared knowledge, my thesis will dive deep into several areas of prominent contention and seek generativity through the generation of novel theories. The thesis structure falls under the framework described by Paltridge (2002) as a 'traditional complex format' comprising "several related studies, each presenting its own introduction, methods, results, and conclusions" (Paltridge, 2002, as cited in Boote and Beile 2005)(p10).

This thesis aims to provide a comprehensive, multi-dimensional interrogation. It responds to calls from previous scholars for an integrated anthropological approach to infant sleep: "With its focus on biological and cultural variation and its multisubfield approach, anthropology is uniquely placed to advance understanding into the landscape of human infant sleep across diverse cultural settings and the varied sleep issues affecting parents and babies in contemporary societies" (Ball, Tomori et al. 2019)(p605). Using the knowledge-seeking tools of anthropology, my work adds to the recent boom of studies utilising a mixed-methods approach[2]. Broadly, the research strategy adopted in the thesis can be regarded as falling within the positivist paradigm in that it focuses upon observation and experiment as means of understanding human behaviour. In this sense, the work utilised anthropology's link to the natural sciences. Via a process known as the "thesis of methodological naturalism" (Maravelakis 2019), it assigns a central role in scientific enquiry to statistical data. In each project, I adopted ontologically realist ideas about what constitutes valid knowledge and about how such knowledge is to be obtained. Phenomena investigated (discrete behaviours) are a "well-defined condition or property that can be recognised if it occurs again" and assumed to be observable via the human senses (Ashby 1957)(p25).

Literature review

Presented in a four-part thematic format, the literature review aims to set the stage for the overall thesis, positioning my work within the ongoing academic dialogue. Following the iterative process of collecting and sorting the literature, my synthesis involved identifying constructs and hypothesizing causal linkages. Common themes were pinpointed, providing a later framework for comparing my own thesis findings with these studies. In the literature review I not only summarize the existing literature but also synthesize it in a way that generates new perspectives. By broadly combining physiological enquiry with social enquiry,

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[2] The number of mixed-methods studies has increased rapidly since 2006; Timans, R., P. Wouters and J. Heilbron (2019). "Mixed methods research: what it is and what it could be." Theory and Society **48**(2): 193-216.

the review builds upon the anthropological hypothesis that the social care of infants is virtually synonymous with physiological regulation (McKenna and Mosko 2001).

Systematic review

This narrative systematic review sought to identify methodological strengths and weaknesses of video-based infant sleep research. Identifying key variables, measures, and methods of analysis in the field, I examined how research practices differ across groups, times, and settings. To address the review question effectively, both qualitative and quantitative studies were included.

Sleep study

This sleep laboratory randomised crossover study investigated hypotheses concerning the impact of swaddling upon infant behavioural parameters (e.g., rooting, crying, active awake). Coding of behaviours involved triangulating biological markers such as oxygen saturation and heart rate with behavioural observation obtained via direct video recording. Infants slept two consecutive nights in the lab – randomly allocated to one night under swaddled conditions and one night under unswaddled (controlled) conditions. Dependent t-tests and Wilcoxon Signed-Ranks tests were performed to test the hypotheses. The study contributes to an established line of laboratory research investigating infant sleep interventions (McKenna and Mosko 1994, Gettler and McKenna 2011, Kahn, Livne-Karp et al. 2020).

Sensor study

This exploratory, proof-of-concept study was motivated by a methodological concern that arose from the literature and lab study (calibrating swaddle tightness) and a desire to address that concern. The project aimed to examine whether a pressure sensor could enable a researcher to standardise the tightness of a traditional swaddle-wrap across numerous attempts. After outlining previous attempts to solve the problem, a randomised cross-over design was employed in which subjects served as their own controls. I applied the sensor to each infant under both experimental (traditional wrap) and control (zip-up swaddle pod) conditions, and recorded the pressure reading at two anatomical points – the humerus and the femur. Paired samples t tests were then conducted to investigate whether consistent swaddling pressure could be obtained by an experienced swaddler, and whether two swaddle types (traditional wrap v pod) produced significantly different pressure at each of the two anatomical points.

Survey

This study contributes to an established line of research investigating the opinions of health professionals concerning swaddling. Motivated by a lack of information pertaining to UK health professionals and a desire to address this deficit, I conducted a mixed-methods exploratory survey of UK health professionals' thoughts, beliefs and observations about swaddling using a 15-item online questionnaire.

Overall discussion

This penultimate chapter summarises and integrates the collective findings from all four projects. Adopting a thematic approach, I explore the many interwoven dynamics embedded in my findings, framing my research in the context of the mother-baby dyad as an integrated unit. I critically explore dominant concepts and offer counterarguments. Further, I generate hypothesis to illuminate a potential mechanism through which swaddling may impact sleep outcomes. Next, I explore maternal use of swaddling as a tool to negotiate the competing demands of the infant and her own needs. After this thematic discourse I present a high-level overview of my contribution to knowledge via this thesis. Finally, I present limitations and reflections, highlighting common themes and challenges, and synthesizing recommendations for further research.

Conclusion

In this closing chapter, I firstly outline the focus of my overall argument. Then, I discuss the significance, meaning and value of my argument to various stakeholders in the field. Finally, I demonstrate what my research may mean for the field and the ways in which my work speaks back to the existing body of research.

Preamble to the literature review

The aim of the literature review is to integrate and critically analyse previous research, to identify central issues and to detail arguments within the field of swaddle study. The goal bares similarity to what Randolph terms a 'phenomenological review', which is to arrive at "the essence of the lived experience of a phenomenon" (Randolph 2009)(p10). To be substantive, thorough and sophisticated, my literature review is presented in the four sections discussed previously: Biobehavioural, Evolutionary, Sociohistorical, and Clinical. Rather than merely providing an exhaustive summary of prior research, my review considers the strength and weaknesses of existing studies and what this might mean for my own research. To quote Boote and Penny, "A substantive, thorough, sophisticated literature review is a condition for doing substantive, thorough, sophisticated research" (Boote and Beile 2005)(p3).

In pursuit of this standard and in consideration of the complex multi-faceted nature of swaddling, the review was conducted as follows: I began by applying broad inclusion criteria, electronically searching academic databases and the internet for literature mentioning swaddling. My search acknowledged the various sub-fields of anthropology, such as medical, sociocultural, and evolutionary anthropology. I scoped the body of literature producing a 'snowball effect' as various themes emerged. Sources were selected on the basis of their comprehensiveness, topicality, relevance, currency, availability, and authority, factors acknowledged to be the ideal framework for coverage in a doctoral literature review (Bruce, 2001, as cited in Boote and Beile 2005). During this process I created hypotheses about the relationships between the themes, synthesising, integrating and amending my work as I went. Once thematic saturation was reached, I performed additional searches of the most prominent themes to generate detail, being mindful to search for contrary findings and rival interpretations.

Chapter 2. Swaddling: an evolutionary review

Introduction

"There is no such thing as a baby, there is a baby and someone."

(Winnicott, 1975, as cited in McKenna 2016).

The goal of this initial literature chapter is to consider swaddling within the comparative context of evolutionary adaptation. Although a relatively neglected area of study, evolutionary processes play important roles in the development and maintenance of infant and maternal health. The conditions of our ancestral environments offer relevant insights into the intersection between adaptive and maladaptive maternal-infant behaviours. Thus we might ask 'In what ways does swaddling replicate or reinforce the evolutionary norms of infancy, and does this matter?'. Although evolutionary history is largely speculative, the availability of anthropological and archaeological data has enhanced the meaningfulness and accuracy of this discourse (Trevathan and McKenna 1994).

The review is presented in three sections. The first section will examine the traits of infants and their evolutionary underpinnings. The second section will detail how these traits determine the type of care infants expect to receive. Discussion will consider the role of the mother as habitat and the mismatch between the separation practices of modern caregiving and ancestral conditions. In the third section of the review, culturally determined expectations and behaviours regarding infant sleep are investigated within the model of parent-offspring conflict theory. The discussion will highlight the contested nature of motherhood and mothering behaviour through an exploration of 'trade-offs'.

<u>Section 1: The Fourth Trimester</u>

"Remember—your baby's brain was so big that you had to 'evict' her after nine months, even though she was still smushy, mushy and very immature; As a result, she isn't quite ready for the big, bad outside world"

(Smith 2013)(p61).

Helplessness and dependency are the hallmarks of human infancy. However, not all baby animals are this feeble. The mammalian neonate, the focus of this review, can be characterised along a continuum of 'altricial' to 'precocial'. Altricial infants are typically born in litters with fused eyes and ears. They have limited neurological development and cannot locomote. Precocial infants, on the other hand, are typically born as singletons with open eyes and ears. They locomote or cling to their caregiver soon after birth. The human infant is born with a peculiar mix of both altricial and precocial traits. Typically singletons, they can see and hear, but cannot locomote or cling. In this sense, they are known as unusually helpless precocial infants (Trevathan and Rosenberg 2016).

Why are human infants born with such contradictory traits? Scholars have advanced a handful of hypotheses to explain this seemingly maladaptive configuration. The most well-known theory is known as 'the obstetrical dilemma' and draws attention to the narrow pelvis of our Hominin ancestors. Whilst this shape enabled the upright human walking style we enjoy today, it did so at a cost. Childbirth with such a narrow pelvis became perilous due to the relatively large-brained infant. The conflict between maternal pelvis size and infant head size created a dilemma necessitating a trade-off between the two. A more modern theory, known as the 'EGG hypothesis' (energetics of gestation and growth), compares neonate body and brain size to maternal body size. The theory highlights a 'metabolic ceiling' whereby maternal metabolism constrains gestation length and foetal growth (Dunsworth, Warrener et al. 2012). Both theories reach the same conclusion – that natural selection grew to favour 'maternal constraint' in which gestation of the foetus is restricted to nine months (Ball 2007). In other words, human infants are born early relative to other species.

In observing the significant neurological immaturity of human infants at birth, some scholars have framed the period between birth and the first 3 months of life as 'the 4th trimester' (Kitzinger 1975, as cited in Stuebe and Tully 2019). Certainly, there is compelling evidence to support an "external gestation period" (Ball 2007)(p3). By the end of their third month, infants have achieved numerous developmental 'milestones' - adaptations to the outside world. By this time, sleep is more consolidated and more representative of a diurnal sleep/wake pattern, many primitive reflexes dissipate, arms and legs uncurl, and neck muscles are strengthened. Also, around this time, infants begin to respond to classical and operant conditioning and demonstrate the beginnings of socially-oriented behaviour. They start to coordinate movements meaningfully in order to reach for objects. The first three months therefore characterise a behavioural transition period from 'foetus' to 'child'. Here, the birth event marks "passage across the bridge between gestation within the womb and gestation continued out of the womb" (Montagu, 1986, as cited in McKenna 2016)(p205), and breastfeeding functions as "a postnatal umbilical cord" (McKenna 2016)(p212).

Section 2: The Mis-Match Hypothesis

> *"Once there was a time of intimate physical contact and tight emotional bonding between mothers and infants, each secure in the other's love, but paradise was lost through the temptations of modernity"*
>
> (Haig 2014)(p32).

Swaddling is often characterised as replicating the uterine environment for the newborn infant, however in contrast to the artificial "mechanical soothing" provided by swaddling (Moller, de Vente et al. 2019)(p2), in utero, infants develop in interactive synchrony with their mother's biorhythms (Klaus and Kennell, 1976, as cited in Trevathan and McKenna 1994). The living walls of the womb (naturally calibrated at body temperature) are in contact with the naked skin of the foetus. These walls comprise several layers that include surface epithelium, networks of blood vessels and nerves, glands and other tissues. In this environment, the foetus is not free of disruptive movement. Rather, she floats, flays and twitches, often in response to the movements of her mother's body (Sansone 2004). The foetus' circadian rhythm is tied to her mother's (Patrick et al, 1982, as cited in Trevathan and McKenna 1994), and this continues postnatally. For instance, after birth, a mother's heartbeat continues to soothe the infant and access to it has been shown to produce greater weight gain in early infancy (Salk, 1960, as cited in Trevathan and McKenna 1994). Interestingly, the pregnant mother's heartbeat is so influentially imprinted upon her infant that it is even shown to accurately predict her infant's later sleeping and crying behaviours. Infants born to low-heart-rate mothers are shown to fall asleep faster, sleep longer, and cry less than those born to high-heart-rate mothers (Smith and Steinschneider, 1975, as cited in Trevathan and McKenna 1994).

Grounded in the behaviour of our hominin ancestors, the human infant is built for continuous bi-directional sensory transaction with their mother (McKenna 2016). Not at any stage of evolution were human newborns prepared for independence whether socially, psychologically or physiologically, nor was this expected of them (Trevathan and McKenna 1994). The prevalence of swaddling (and other parental sleep strategies) therefore diminishes the 'goodness of fit' between evolutionarily-derived infant sleep/behaviour patterns and cultural expectations for sleep/behaviour (Jenni and O'Connor 2005). The swaddle barrier decouples maternal-infant physiological synchrony. It impedes both visual and physical contact, and is therefore at odds with the evolutionary imperative of humans as a “continuous contact” species (Shad, 1963, as cited in Stuebe and Tully 2019). Indeed, anthropologists have for decades highlighted tensions between contemporary infant care practices and maternal and infant evolved biology (Ball and Russell 2012). As Heller outlined,

> *"While in contact with the mother, the infant’s systems are kept at a regular tempo. But apart, the newborn must work doubly hard to maintain physiological harmony.”* (Heller 1997)(p31).

When viewed through this lens, the fourth trimester is intended to take place on the mother’s body, not in a container. The mother’s body is regulatory and responsive in contrast to the artificially ‘engineered’ constraint of swaddling. The maternal habitat provides infants with the opportunity to respond to stimuli and make instinctive behavioural and physiological adjustments, supporting these as necessary, rather than suppressing evolved responses.

Even if swaddling technology advances to the point where it could simulate a robust replica of uterine conditions, the needs of an infant are distinct from the needs of a foetus. An example can be found in the postnatal functionality of reflexes. Swaddling supresses a wide range of infant reflexes. Crucially, evidence suggests that reflexes evolved as a brainstem-mediated response to physiological and social challenges of the extra-uterine environment. For instance, activation of reflexes alone has been shown to cause recovery from obstructive sleep apnoea (Remmers, deGroot et al. 1978, Thach 2002). The startle enables infants to lift their head in reaction to respiratory obstruction (McGraw 1963, Paluszynska, Harris et al. 2004), whereas the asymmetrical tonic neck reflex (or ‘fencer’ position) provides stability and control, helping the infant to organize himself and attend to his environment (Nugent 2011). Additionally, the Moro reflex was considered by Rousseau et al to represent a ritualized behaviour of nonverbal communication whose meaning is a request to be picked up in the arms (Rousseau, Matton et al. 2017). In this view, the gestures associated with the Moro reflex: crying and orientation of the body, head, and eyes towards a human person, could be gestures of intention to communicate.

The biological makeup of the infant is designed for extra-womb conditions. This environment provides diverse sensory input that is distinct from that provided by the closed environment of the womb. The importance of the difference between intra-womb stimuli and extra-womb stimuli has been explored by scholars through ‘the ontogenetic hypothesis’. This theory draws attention to the predominance of active sleep (AS) experienced by the fetus in the womb. It posits that such a high degree of foetal AS - at least 70% of all sleep (Pillai and James 1990) - is an adaptive response that ensures optimal neural growth, and importantly, counteracts the under-stimulative confines of the uterus. In this sense, AS is an "internally generated form of substitute stimulation" (Horne 2000)(p778). Through this lens, Horne argues that compared with Quiet Sleep (QS), AS may not be ‘true sleep’ but rather a way to supplant wakefulness when the latter is unproductive or unstimulating (Horne 2000).

Supporters of the ontogenetic hypothesis link the decline of AS following birth to the abundant presence of real, novel sensory stimulation of the extra-womb environment (Roffwarg et al, 1966; Coons and Guilleminault, 1982; Fagioli and Salzarulo, 1982; Victor and Evelyn, 1981, as cited in Horne 2000). With reference to swaddling, studies of heart rate suggest that, rather than being under-stimulating, it is more likely swaddling provides the *wrong* sort of stimulation. As will be seen in the biobehavioural review, swaddling increases respiratory frequency linear to the tightness of the wrap, alters arousal processes, and prolongs sleep. Infant physiology has not adapted to remain in tight womb-like conditions and thus continuation of such stimulation is mismatched to infant needs.

The ontogenetic hypothesis is the only theory to address the predominance of AS in utero and its decline during the fourth trimester. Following this hypothesis, swaddling, by acting as a facsimile of the womb, inappropriately-stimulates the brain during a window of rapid development. Indeed, the womb-like design specifies the swaddle’s pressure-inducing yet restrictive function, and in doing so, imposes a particular regime of function on the end user. A 'conversation' occurs between the swaddle and its occupant infant in a way that nudges the infant's behaviour in a particular direction. As Frenken critiqued, "[Through swaddling] an active baby turns into a creature, which is more passive than the foetus ever was" (Frenken 2011)(p238). The sensory deviation of swaddling is mismatched to the evolutionary expectation that infants function in the specific sensory environment of their mother's arms.

The importance and uniqueness of maternal physical contact to healthy postnatal infant development was demonstrated by the behavioural experiments of Harlow (Harlow and Harlow, 1962; Harlow and Harlow, 1965, as cited in Trevathan and McKenna 1994). In his famous surrogate mother experiment, Harlow took infant monkeys from their biological mothers and gave them two inanimate surrogate mothers: one was a primitive construction of wire and wood, and the second was covered in foam rubber and soft terry cloth. Overwhelmingly, the infant monkeys preferred spending their time clinging to the cloth mother, even when food was only available from the wire mother. Harlow concluded that 'contact comfort' was therefore essential to the psychological development and health of infants. In a similar vein, later scholars found that 'anxiously attached' human infants tended to have mothers who were averse to close body contact (Ainsworth, 1978, as cited in Trevathan and McKenna 1994). Studies demonstrate that extensive postpartum separation can result in styles of care-giving that are poor or abusive and produce fearful and socially inept infants (Barnett et al, 1970; Elmer and Gregg, 1967; Klein and Stern, 1971; Sameroff and Chandler, 1975, as cited in Trevathan and McKenna 1994).

Arguably therefore, separation of mothers and infants through swaddling provides a sub-optimal quality of care. It is a contemporary modification that differs from that previously experienced in human lineage. Rather than providing infants with the comforting nostalgia of the womb, swaddling may be experienced as a developmental stressor, given that the infant's system is required to perform under conditions outside of its evolutionary remit (Haig 2014). Through swaddling, the embodied relationship of mothers and infants is disrupted.

Section 3: Mothers and Infants - Co-operation or Conflict?

> *"If mothers tied their children from head to feet so that they couldn't respond to tickling, clucking, and cajoling, it must mean the mothers had little interest in such things in the first place."*
> (Shorter 1975)(p29).

Although mothers and infants share an embodied relationship, they can also be considered individuals with often conflicting needs. Parent–offspring conflict theory was first conceptualized by Trivers in 1974 (Trivers 1974). The hypothesis recognises that infants are naturally selected to seek more parental resources than is in the caregiver's best interest to provide (Stuebe and Tully 2019). Further, parents are naturally selected to balance parental investment across current and future offspring. Schlomer and colleagues argued that the 'intensity' of conflict depends on the *degree* to which parent and infant needs clash (Schlomer, Del Giudice et al. 2011). This can be understood as the gap between the parental and the offspring optima. Getting their offspring to reproductive age at the lowest possible cost is the 'optimum' parental strategy in evolutionary terms, whilst maximizing their future reproductive success is the optimum infant strategy. The *nature* of the disagreement between mother and infant predicts how the conflict is resolved (Kuijper and Johnstone 2018). Mothers have the capacity to control the nature of the disagreement by controlling what information the infant receives about the environment and thus manipulate infant size in utero. It is in foetus's interests to be as large as possible, but in the mother's interests to limit foetal size in line with her metabolic resources. She can do that biologically by limiting nutrients to the foetus (Kuijper and Johnstone 2018). Swaddling can function similarly. In tightly wrapping their infant, mothers arguably "win" the conflict by providing offspring with limited degrees of information (Pen and Taylor 2005; González-Forero 2015, as cited in Kuijper and Johnstone 2018).

A key concept within parent-offspring conflict theory is that of parental investment. This variable is categorised by the degree to which parents invest in their own growth and maintenance versus their offspring's growth and maintenance (Mulder 1992, Dixley 2014, Ball, Tomori et al. 2019). In other words, mothers must plot the best way to invest in their children, considering the personal costs incurred in undertaking such efforts. Investment in an individual offspring increases that offspring's chance of surviving (and hence reproductive success) at the cost of the parent's ability to invest in other offspring (Trivers 1972)(p139). In this respect, it could be said that the way mothers manage the dispersal of their parenting resources demonstrates a finely-tuned 'maternal response system' that is calibrated to particular contexts and conditions" (Volpe, Ball et al. 2013)(p93). In response, infants of all species have adapted a wide repertoire of behavioural tactics designed to motivate parental investment. These include crying, fussing, and cue-giving (Hinde 2014). Through these "psychological weapons" (Trivers 1974)(p249), infants function as dynamic agents in their own development, procuring and shaping maternal effort (Fairbanks and Hinde 2013).

Maternal-infant conflict is underscored by phylogeny. Our species' evolutionary history has provided infants and parents with distinct, often conflicting, needs. For instance, as infants have different surface-to-volume ratios that result in more rapid loss of heat, they have different thermoregulatory needs to mothers. Body contact is thus a survival imperative for infants. Infants' "emotional proclivities" (i.e. crying) evolved in an environment in which maternal separation (however brief) appropriately signalled danger {McKenna, 2016 #1962}(p218). In a broader vein, sensory stimulation in the form of touch is considered a basic biological and physical infant need (Fleming and Gonzalez 2009). Infants require body contact for feeding, which is often frequent, as breastmilk is easy to digest and therefore digested quickly. Although 'extended breastfeeding' (defined in America as breastfeeding beyond 1 year) is beneficial for infants, *maternal*, rather than infant, initiated weaning from the breast is a practice seen across human cultures. In the Turkana pastoralists of Kenya, for instance, the infant is left in the care of alloparents for durations from a few hours to a few days (Schlomer, Del Giudice et al. 2011). Swaddling may encourage weaning in a similar separative fashion, even in newborns. Indeed, scholars have drawn parallels between cultures in which infant sleep interventions are popular and poor rates of sustained breastfeeding (Ball 2020).

In the context of mother-infant conflict, feeding is intimately connected to sleep. Infants need to wake frequently to feed throughout the night whereas adults function optimally on prolonged bouts of sleep (Bonnet 1993). Some argue that swaddling may *promote* breastfeeding by increasing infant sleep. Adopting this view, Karp maintains that swaddling strengthens the resolve of mothers who would have otherwise quit breastfeeding due to such factors e.g. sleep disruption (Karp 2020).

The link between infant behaviour and maternal depression has been attributed, in part, to subjective perceptions of 'excessive' infant crying (Vik, Grote et al. 2009, Petzoldt 2018). Following parent-infant conflict theory, crying involves a bid at control from infant to parent (Boukydis and Lester 2012). In this context, swaddling is espoused as an 'antidote' being associated with a decrease in the duration of time infants would otherwise spend crying (Caiola 2007, Karp 2007, van Sleuwen, Engelberts et al. 2007, Akhnikh, Engelberts et al. 2014). In other words, swaddling reduces the costs of infant care. Data suggest that, after one week of use, swaddling is equally effective in decreasing crying as other, arguably more labour-intensive, parenting interventions such as the introduction of regularity, stimulus reduction, and uniformity into an infant's daily care (Nelson 2017). These findings have led critical scholars to claim that swaddling "disengages" infants from dependency social relationships (Keller, Lohaus et al. 2004) (p29) and inserts a "battleground" mentality into the mother-infant relationship (Stuebe and Tully 2019)(p79), (Schlomer, Del Giudice et al. 2011)(p498).

As crying is costly in energy terms, any misrepresentation of need on behalf of the infant is selected against (Godfray 1995) meaning that crying evolved as a genuine distress signal (Lester and Boukydis 1985). Nonetheless, infants that cry intensely for prolonged periods of time are at increased risk of parental mistreatment (Reijneveld, van der Wal et al. 2004). In the U.S., the Prevent Child Abuse Ohio (PCAO) 'Love Me…Never Shake Me' parent education program recommends swaddling as a means to reduce shaken baby syndrome (Deyo, Skybo et al. 2008). Paradoxically however, when their hands are restrained, infants cannot self-regulate by sucking on their fingers or hand, behaviours shown to reduce crying (Gribble 2006).

In contrast to infants, whose needs are clearly biased towards biological requirements, maternal needs may appear predominantly social in character. However, once interrogated, maternal needs reveal their biological origin. For instance, mothers in industrialised societies balance investing in infant care with investing in waged employment and domestic activities. Both options enhance fitness, the former by enhancing infant survival whilst the latter benefits existing children and other family members (Ball and Russell 2012, Kramer and Veile 2018). Perception of everyone's needs, familial influences, and resource availability and accessibility therefore intersect to nudge parents towards particular 'trade-offs' (Lau and Hall 2016).

The higher the number of surviving offspring that go on to reproduce, the greater a mother's lifetime reproductive success. A trade-off dynamic therefore exists between number of surviving offspring and the survival of individual offspring (Haig 2014). This dynamic often inclines mothers towards increasing their number of reproductive events. Indeed, the optimum Inter-Birth-Interval (Nelson, Taylor et al. 2001) is thought to be shorter for parents than the optimal IBI for infants (Haig 2014). This conflict is weaponised on both sides. Infants can manipulate a mother's fertility through their interactions with her, potentially delaying the conception of a younger sibling who would otherwise compete with the existing infant for parental resources. For instance, in primates a high probability of conception is associated with a lower rate of interaction with current offspring (Maestripieri 2002). Similarly, in humans, frequent night feeding suppresses ovarian function, a process called lactational amenorrhea (Howie and McNeilly 1982, Jones and da Costa 1987, Heinig, Nommsen-Rivers et al. 1994). Maternal fatigue can also extend IBI, therefore increasing infant fitness but reducing maternal fitness (Haig 2014).

Swaddling, as a maternal behaviour, works to counter-act infant-initiated conflict. The intervention increases sleep and can also undermine lactational amenorrhea by reducing feed attempts (Taheri 2006, Bystrova, Matthiesen et al. 2007, Lavner, Stansfield et al. 2019). The practice is likely to have emerged as a 'solution' to problems relating to parental investment. The wrap serves as a mere caricature of maternal investment. Given that the 'essential' mothering function (defined by Harlow as 'comfort') can be extracted and duplicated via swaddling, the practice renders maternal labour as dispensable (Franzblau 1999).

Swaddling exaggerates the power imbalance between mother and infant, creating a conception of the dyad as 'child-as-object' and 'adult-as-subject' (Zornado 1997). The relationship of the subject to the object is mediated through the swaddle. In this vein, Zornado argues that swaddling represents an ideology of parent-child relations in which the parent "colonizes" the child and demands that the child accept this process (Zornado 1997)(p105). The procedure of wrapping and tightly binding the infant is an explicit demonstration that the parent has sole power over the infant's body. In extreme terms, "short of killing the child, swaddling represented the most effective method of control" (p106). Following this view, some scholars have advanced the idea that evolution favoured the formation of a *weak* mother-infant attachment (Johow, Voland et al. 2014, Keller, Otto et al. 2014, Lancy 2014, Weisner, Otto et al. 2014). They suggest numerous fitness benefits of weak attachment and reduced investment. Among these, include a mother's motivation to become pregnant (Lancy 2014).

Conflict and Maternal Interpretations of Infant Behaviour

The first weeks of parenthood have been characterised as a period of "profound disorientation" (Tomori and Boyer 2019)(p1180). Although frequent infant arousals and the need for close proximity are biologically appropriate, mothers have reported feeling "shocked" by such behaviours (Lau and Hall 2016)(p2820) and describe sleep resistance and bouts of crying as "vividly agentic" and problematic (Tomori and Boyer 2019)(p1181). Sleep, (perceived lack of) and crying, (perceived excess of) are major concerns and preoccupations for new parents (Ball, Taylor et al. 2020). Consequently, much attention has been devoted to parental acquisition of information about the validity of infant crying and the potential for infants to exaggerate or misrepresent their needs (Godfray 1991; Godfray and Johnstone 2000; IE: Royle et al. 2002; Wells 2003, as cited in Kuijper and Johnstone 2018). Inventions such as the Snoo[3] are examples of commercial interests capitalising upon this conflict. The swaddling bassinet has an integrated smartphone app which monitors infants' biometrics and suggests to parents when the infant may require a feeding or nappy change. In doing so, the Snoo eliminates the need for parents to physically check the infant. In other words, the information it supplies informs parents to what extent they can rely on offspring signals. The creator of the Snoo has espoused the elimination of checking as producing a better quality of life for parents (Vest 2020). Part of the family of 'shush and pat' interventions, the Snoo and its predecessor, traditional swaddling, are replacements for parental soothing (Moller, de Vente et al. 2019)(p2). Examples of 'surrogacy parenting' (Luijk, Kok et al. 2020), their ultimate aim is to teach infants to self-settle without dependence on feeds or being held (Douglas and Hill 2013).

Of course, caregiving imperatives are culturally relative. Cultural context influences the ultimate costs and effects of night waking, as subjectively perceived by mothers (McKenna 2014). In relation to sleep, western mothers are taught to expect an adversarial relationship with their infants (Schaefer, 1992, as cited in McKenna 2014). This is confounded by interventions like the Snoo and traditional swaddling which have further manipulated parental expectations of 'normal' infant sleep (Ball and Russell 2012). Along with cultural priorities, the perceived necessity of interventions can influence some parents to *interpret* frequent infant awakening as a pathology requiring treatment. In this scenario, "the parent experiences a problem, and the baby is pathologized" (Ball 2020)(p164). Around a quarter of parents believe that their child has a sleep problem (Owens 2005), many stemming from "expectations for rapid transition from wakefulness to sleep" (Jones and Ball 2012)(p98). In this context, swaddling can be a way to shoehorn human sleep physiology into the narrow mould of cultural expectation.

Conclusion

> *"For species such as primates, the mother is the environment" {Hrdy, 2000 #1301}(p69).*

In the above citation Hrdy echos this chapter's opening quote of Winnicott, positioning infant needs and parental responses as dynamic and interdependent. An appreciation of the intertwined nature of maternal-infant biology enables a more accurate critique of physiology and behaviour. This review has highlighted the uneasy marriage between the notion of mother as habitat and the belief that 'technology' in the form of a swaddle can act as a reasonable facsimile of the mother. The modern culturally-derived environment poses the

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[3] The Snoo is a "self-rocking, self-shushing, white-noise-making, internet-enabled bassinet", costing around 1,000 GBP Peck, T. (2020). "Priceless or overpriced: Is the wifi-enabled Snoo baby cot worth the £1,000 price tag? We put it to the test."   Retrieved 18/10/2021, from https://www.independent.co.uk/extras/indybest/kids/baby-tech-essentials/snoo-smart-sleeper-baby-cot-bassinet-review-pod-test-uk-a9470376.html.. Integral to its design is a swaddle wrap affixed to the bassinet mattress.

backdrop to which mothers navigate their parenting expectations. In contrast, infant biology reflects long-term adaptation to a vastly different micro-environment from that provided by contemporary swaddling. Indeed, swaddling is paradoxical as it deprives the infant of the rich sensory environment of their mother's body while bombarding the infant with artificial stimulation in the form of an unexpected restraint.

Ultimately, for reasons of survival, the parent-offspring relationship is not an equal nor reciprocal one. The dichotomy of the binder and the bound is rife with tension, and cultural ideologies reveal conflict between reproductive and productive work. Within this context, mother–infant behavioural outcomes are the sum of elaborate negotiations. Indeed, conflict within the dyad is as much part of human biological heritage as the sharing of love. Within a broader appreciation of evolutionary paediatrics that considers intergenerational conflict, swaddling may not seem as 'unnatural' as a purely artefactual view would assume. The swaddle intervention is a method through which mothers control offspring. It is a maternal strategy employed to address mother–infant conflict, a representation of the instinct to maximise one's own fitness. Swaddling reduces maternal investment by obviating the infant's requirement for the touch, nutrition and comfort of the maternal habitat. In this vein, the swaddle wrap provides environmental cues that differ from those anticipated by evolved infant bodies.

In the absence of longitudinal research, the developmental effects of swaddling cannot be certain. That swaddling is performed at a time of great developmental plasticity should caution parents, practitioners and policy makers to its instrumental potential.

Chapter 3. Swaddling: a sociohistorical review

> *"And she brought forth her firstborn son, and wrapped him in swaddling clothes, and laid him in a manger; because there was no room for them in the inn" [Luke 2:7, King James Version (KJV)].*

The most famous story of swaddling is found in the New Testament concerning the birth of Jesus. Wrapping of infants has featured cross-culturally throughout history from antiquity to modernity. Swaddled infants have been found in Egyptian tomb relics dating back to 2500 BC, and some suggest that the practice dates back to the palaeolithic period (Hudson and Phillips 1968, DeMause 2002). Is swaddling merely an 'accidental survivor' of an earlier era? That the practice has been preserved for millennia warrants investigation, and several questions emerge: To what degree, if any, is swaddling influenced by changing economic/philosophical/religious zeitgeists? Does swaddling reflect cultural and historical beliefs pertaining to personhood, humanity and the concept of infancy? What evidence is there to position swaddling as a socialization and humanization strategy? And finally, how does swaddling reflect cultural and historical beliefs about how infants' bodies are handled and treated by caregivers?

This review will seek to answer these questions using theoretical frameworks from anthropology, and will complement the numerous historical reviews of swaddling that have been conducted previously (Zornado 1997, van Gestel, L'Hoir et al. 2002, Frenken 2011, Frenken 2012). The novelty of this review, however, is that it performs a *socio*historical interrogation of the practice through synthesizing historical *and* cultural data. Firstly, historical and ethnographic texts mentioning swaddling were subjected to qualitative analysis. Then, common themes were identified as well as dimensions of cross-cultural variation that underpin basic motivational processes across populations. Finally, the data were synthesized thematically. Examples are given that are representative of the wider data set, chosen to illustrate the main ways in which themes were presented across texts. The ultimate aim of this review is to explore the social and cultural dimensions of infancy, and to identify and investigate the ways in which infants' bodies have been conceptualized, as reflected in swaddling practices.

Readers of this review should be mindful that there is no such thing as "a neat cultural package" (Tomlinson 2003)(p46). Although the review will highlight historical changes and intercultural variations, it is important not to assume societal consensus or to over-prescribe differences between cultures or historical epochs. While reading, one must guard against developing an ethnocentric and historically linear world view of swaddling and instead consider the vast diversity not just amongst nationalities, but also amongst distinct cultural groups. Global, macro-level changes in immigration, political and economic trends, and technological advances mean that nationalities cannot be succinctly classified in discrete cultural terms (Tamis-LeMonda, Way et al. 2007). Rather, using the theoretical frameworks presented, one can more usefully understand communities and their swaddling practices in terms of common trends.

Infancy, embodiment, and personhood

This section of the review will configure infancy, embodiment, and personhood through the lens of the swaddling practice. Concepts of infancy, embodiment and personhood are regarded as interwoven ideological constructs because, as will be demonstrated, the infant body cannot be studied as an entity distinct from culture, rather it is the *subject* of culture (Csordas 1990).

The invention of the term personhood is thought to date back to European philosophical discourse during the Age of Enlightenment (1715 - 1789) (Obladen 2018). From the concept of Personhood grew the ideas of consciousness and natural rights. Within this burgeoning ideological backdrop, eighteenth century Swiss philosopher, writer, and social theorist, Jean Jacques Rousseau asserted that swaddling was unreasonable and unnatural, and that infants needed freedom. In his popular work *Emile* (1761) he wrote:

> *"From the moment that the child breathes on leaving its envelope, do not suffer his being given other envelopes which keep him more restricted: no caps, no belts, no swaddling... When he begins to grow stronger, let him crawl around the room. Let him spread out, stretch his little limbs. You will see them gaining strength day by day. Compare him with a well-swaddled child of the same age; you will be surprised at the difference in their progress"* (Rousseau, 1761, as cited in Harris and Douny 2016).

Notice the initial reference to the uterus as an 'envelope'. Here, Rousseau asserts that infants should not exit the uterus only to be placed in other uterus-type restraints. Exiting the uterus is viewed as the definitive point at which socio-moral recognition of infant personhood takes place.

In anthropological discourse, personhood is a fluid analytical term used to indicate who, within any given culture, is considered to be a fully functioning and accepted member of that culture (Quante 2020). In some societies, infancy is viewed as a transitional period in which personhood and personality are imminent but not assured (Conklin and Morgan 1996). In this vein, swaddling is an instructive example of how conceptualisations of personhood are communicated through customs. For instance, some cultures believe that infants are 'unfinished' people (Shilling, 1993, as cited in Lupton 2013). A distinction is drawn between "biological birth", the exiting of the infant from the uterus, and postnatal "social birth", specific rituals performed later that grant personhood (Conklin and Morgan 1996)(p677). Here, infancy is a state of marginality and liminality: alive but not yet an accepted person (Dann 1999). Personhood is denied on grounds of immaturity, however through transformative prescriptions (e.g. swaddling) personhood can be met (Bonnet and Arand 1997, Greenway 1998). In essence, swaddling bridges the gap between being and non-being. In Kazakhstan Iraq, for example, newborns are swaddled for their first 40 days, after which a celebration is arranged for the "true, second birth of a child, the birth in the real world" (Zhanar, Karlygash et al. 2019)(p112). This celebration, known as *shldekhana*, commemorates moving of the infant from swaddle to cradle, marking the end of infant liminality. After *shldekhana*, infants are dressed just like adult men and women (Shireen 2014).

Similarly, the Wari of Amazonia adopt the concept of the 'external womb' (Morgan 2009). After biological birth, the infant remains socially unborn. Here, mothers and their infants are considered as inseparable postnatally as they were before birth (Conklin and Morgan 1996). Amazonian infants are swaddled and attached to their mother with a piece of material contributed by the father. This custom is believed to strengthen the weak infant body in preparation for personhood (Conklin and Morgan 1996, Lancy 2014). Indeed, cultural perceptions of the infant body are integral to the social production of personhood (Conklin and Morgan 1996). Aside from its biological essence, the infant body is a vessel for social and cultural ideology, and this in turn, determines how infants' bodies are handled and treated by caregivers.

Infant body as unripe

A common theme in both the historical and ethnographic literature is the infant body as 'unripe'. As eluded to in the Wari example above, many cultures view infancy as a time of transition that evokes conflicts between change and continuity, integration and disintegration (Conklin and Morgan 1996). In fact, a Wari infant is known as *arawet*, which literally translates as "still being made" (Conklin and Morgan 1996)(p672). Accordingly, infants are compared to unripe fruit in Amazonian tribal culture (Morgan 2009). A similar food metaphor is used by the Pashtu of Afghanistan. Here, tribeswomen argue that newborn flesh is *oma* (unripe) like uncooked meat, and that only by swaddling will it become strong (*chakahosi*) and solid like cooked (*pokh*) meat (Dyer 2012). An ontology of the infant body as unripe was present in Europe as far back as the sixteenth century when newborns were washed and rubbed with salt to thicken their skin before being tightly swaddled in linen bands from head to toe (Shorter 1975). Resting routinely upon the infant's skin and serving skin-like functions, the swaddle becomes a prosthetic skin or "super-skin" (Allerton, 2007, as cited in Lupton 2013)(p8). It can protect and hide the body and may become imbued with bodily substances. In contemporary Romania, newborns are starved for the first three days of life, swaddled tightly in their parents' clothing and tied up with a chain to make them "strong as iron" (Borbely 1999, Dervin 2008)(p27, p220). Likewise, most contemporary Turkish infants are swaddled at some point during the first year of life (Caglayan, Yaprak et al. 1991, Kutlu, Memik et al. 1992, Akman, Korkmaz et al. 2007, Okka, Durduran et al. 2016) until they "seem strong and healthy" (Delaney 2000) (p131). Turkish parents believe that swaddling straightens and strengthens the arms and legs and wrap their infants as tightly as possible.

Indeed, for the unripe infant body, swaddling is viewed as a moulding instrument. In Native American cultures, swaddled infants are placed on a cradleboard via the lacing of strings or strips of cloth passed over the body (Thompson and Joseph 1958, Hail 1999). This configuration is believed to "make them straight and strong" (Leighton and Kluckhohn 1947)(p23). The moulding process can be lengthy; Navajo Indians use cradleboards within a few days of birth and continue for up to 2 years (Chisholm 2017). The daily amount of time spent in this condition varies across infants, averaging 60% to 70% in the first 6 months of life and 30% later (Chisholm 2017).

Infant body as foetal

A much older and more humanistic ideology to the unripe metaphor is the conceptualisation of infants as foetal-like. This paradigm can be traced back to ancient history (6,000 BCE – 650 CE). In ancient Latin, the word *fetus* is equally applicable to a child in utero and a newborn (Traig 2019). The ancient Greeks saw no distinction between the unborn child in the womb and the breastfeeding infant (Dann 1999). Plato compared the newborn to an embryo and to the malleable nature of wax (Frenken 2011). Indeed, the malleability of the infant body caused great concern amongst medical authors of the time (Dasen 2011). The ancient physician Soranus (Approx 100 AD) prescribed tight swaddling as essential in moulding the infant's body and preventing deformation (Frenken 2011). The practice was even espoused to offer protection from cerebral palsy, a belief that endured for centuries. Certainly, Plato was so convinced of the virtues of tight wrapping that he proposed a swaddling law (Obladen 2011).

Aside from its medicinal functions in correcting a malformed foetal state, Romans considered swaddling a symbolic birth rite that separated mother from infant after delivery (Hänninen 2005). In this context, a feminist interpretation positions swaddling as a tool of patriarchal control. As motherhood was women's only source of authority and social recognition at the time, men were motivated to instruct separative practices immediately after birth (Bell 2013). Prior to swaddling, Greek and Roman newborns were 'salted' with soda ash to harden their skin for extrauterine life (Lipton, Steinschneider et al. 1965), and then tightly wrapped to "eliminate traces of uterine life that cling to the child" (Dasen 2009)(p212). The process would set in motion a *transition* 'from womb to [male-headed] family' (Hänninen 2005). It is difficult to ascertain how Roman mothers felt about swaddling as their voices within historical records are "deafeningly silent" (McAuley 2015)(p4). Certainly, records indicate the equally silent infant was not recognised as a full member of the community while in the womb and while swaddling, rather, in both senses were deemed 'unborn' (Graham 2013).

The symbolism of swaddling as separative and transformative continued into the European middle ages. Swaddling of Tudor infants involved placing the legs together and the arms at the sides; a piece of white dimity or other strong material was then wound around the infant to enclose its arms and whole body. Finally, a swaddle band was wrapped under the infant's chin and over the forehead to secure the head, and then wrapped around the body down to the ankles (Shorter 1975). These swaddle wrappings were thought to hold 'nourishing juices' (Tucker 1985). Eighteenth-century English infants were left tightly wrapped for days or even weeks in the same swaddling clothes. To change the swaddle on a regular basis was believed to rob the infant of its nourishing juices (DeLoache and Gottlieb 2000). The reference to nourishment may be an attempt to replicate and replace the uterine environment.

The ideology of infants as foetal continues amongst several contemporary cultures. Latino American families believe that swaddling de-stimulates infants and helps them to maintain the sense of security and control they had in the womb (Maldonado-Duran and Lecannelier 2019). Similarly, Chinese paediatricians argue that swaddling, by keeping the limbs in a flexed position, facilitates the developmental transition from the womb (Ye 2006). The association of swaddling with uterine conditions is also favoured by the Māori of New Zealand. Here, the term *kahu* is used to describe both the amniotic sac and the woven cloaks that serve as important tools during the time of childbirth. The *Kahu* cloaks are then used as wrappings to swaddle the newly born infant (Henare 2005). A similar dynamic can be found in Indonesian communities. Here, the placenta is viewed as a twin sibling and the swaddle as an "artificial skin" replicating the protective function of the amniotic sac (Shore 1997)(p38). For these reasons, the newborn, together with its still-connected placenta, are swaddled in a sarong immediately after birth (Errington 1983).

Infant body as physically vulnerable

Interwoven with the perception of the infant body as unripe/unfinished and foetal is the globally widespread belief in infant physiological vulnerability. In Poland, parents view their infants as exceedingly fragile and apply swaddling as a means to “harden” their child (Benedict 1949)(p345). Malaysian infants are also swaddled for this reason (Yaman 1996). Likewise, in India, more than half of caregivers believe that swaddling is essential to keep their infant’s legs strong (Pinto, Aroojis et al. 2021). Similarly, Iranian mothers swaddle their infants to strengthen and elongate the body and to contribute to good posture (Kendall 1992). In neighbouring Jordan, swaddling is deemed the only acceptable way to clothe a young infant (Abuidhail 2014). The practice is especially common during the first two months after birth, although may last as long as two years (Jarrah and Bond 2007, Abuidhail 2014, Al-Sagarat and Al-Kharabsheh 2016). Indeed, in Jordanian culture, swaddling is thought to procure numerous physiological benefits. These include, strengthening and straightening the limbs and body (Abuidhail 2014), preserving warmth, and preventing respiratory disease (Mrayan, Abujilban et al. 2018). The swaddle sheets are usually coloured yellow as it is believed this colour can prevent or cure jaundice (Özen and Özgör 2006, Çetinkaya, Özmen et al. 2008, Örsal and Kubilay 2009). They are typically applied very tightly, restricting all movement, a technique considered by most Jordanian mothers to be safe (Abuidhail 2014). In addition to this, another centuries’ old aspect of Jordanian swaddle technique, known as *höllük*, is performed. This procedure involves filling the swaddle with heated soil, thought to reduce the need for frequent nappy changes. Despite being the dominant cause of neonatal tetanus (Güleç 2000, Özen and Özgör 2006), Jordan mothers maintain that “a child grown without sand will not be able to hold his urine, will have haemorrhoids, get ill frequently, get cold and have knee pain” (Bahar and Bayık 1985). Through protective rituals such as *höllük,* the swaddle wrap becomes a performative object that signifies and indeed forms part of, the performance of good parenting.

The Ifaluk people who inhabit the central Caroline Islands of the Pacific Ocean regard the first three months of life as vulnerable and address this with swaddling. In Ifaluk culture, to swaddle is to sweat, an outcome that is viewed as a positive and desirable (Le 2000). Ifaluk infants are placed on a floor mat and swaddled completely in the hope of encouraging perspiration. If done regularly, this procedure is thought to help the infant to grow properly. Similarly, in Uzbeki culture, swaddling with legs straight is believed to support "accurate lying of the baby" (Mashrabjonovna 2019)(p4832), despite significant evidence associating it with developmental dysplasia of the hip (Loder and Skopelja 2011, Blatt 2015). Prior to being swaddled, infants in Uzbekistan are massaged, a custom thought to prevent "cradle mould" - deformity of the arms or legs (Mashrabjonovna 2019)(p4832). These exemplars frame swaddling as a medicinal antidote to the vulnerability of the infant body. Certainly, the ideology of vulnerability positions the infant body as a dependent and passive object (Christensen 2000), as illustrated in rural Thailand where caregivers believe that newborns cannot see, and swaddle their infants in fabric hammocks that allow “only a slit view of ceiling or sky” (Bornstein 2012)(p215).

A conceptualisation of the infant body as immature, fragile and vulnerable can also be seen in contemporary European discourse. In this culture, "the body which is tightly contained and controlled, its boundaries rendered as impermeable as possible, is championed as a cultural ideal" (Lupton 2013)(p47). Here, infant vulnerability is meshed with the view of infants as 'unpredictable' and swaddling as a tool to tame "chaotic bodies" (Lupton 2014)(p348). Evidenced in the omnipresent commercial narratives of infant safety products, any sign of infant mobility is interpreted as a risk to their safety (Martens 2014). The European motivation to swaddle to protect from dangerous movements exemplifies this view. This ideology, common in Turkey, Poland, Russia, and Romania, substitutes swaddling for the watchful prevention a parent might give (Geçkil, Şahin et al. 2009, Harkness, Zylicz et al. 2011).

Infants are also swaddled for safety in cultures with potentially hazardous environments, such as when animals, farm tools, open fires, and dangerous terrain, are in the immediate vicinity (Karasik, Tamis-LeMonda et al. 2018, Zaxlacki and Derrick 2020). The immobilization of the infant via swaddling, often for relatively lengthy durations, serves to protect their safety in these physical settings. In the post-Soviet country of Kyrgyzstan, immobilization of the arms and legs is seen to protect the infant from exposure to animals and open fires (Zaxlacki and Derrick 2020), and in Iran, a small loaf of bread is attached to the swaddle by a band, a ritual believed to protect the infant from cats (Kendall 1992).

Infant vulnerability to climate serves an additional motivating factor to swaddle. Iranian infants are typically swaddled for up to nine months if the weather is colder, or five months if the weather is warmer (Kendall 1992). Swaddling is particularly popular in the East-Asian country of Mongolia during the cold season. Mongolian climate is strongly continental, with long, frigid winters and short, warm summers. The Mongolian swaddling technique involves "tight, prolonged wrapping from the head or neck down in two to three layers of thin cotton cloth, covered by layers of thick blankets or sheepskin" (Tsogt, Manaseki-Holland et al.

2016)(p152). Infants are swaddled day and night from birth until at least 2 months of age (Narangerel, Pollock et al. 2007) when it continues with a gradual decrease in intensity and duration until around 6 months (Tsogt, Manaseki-Holland et al. 2016).

Infant body as mortal

Connected to the realization of the infant body as vulnerable is the poignant observation of the infant body as mortal. The ancient Greeks lamented the omnipresence of infant death and because of the anxieties it created, deemed affectionate feelings towards infants "too expensive" emotionally (Dann 1999)(p56). In contexts where the risk of neonatal death is very real and multiple, swaddling serves as a 'dehumanizing' custom which helps parents to resist forming an emotional bond to their infant (Lancy 2014). Swaddling separates and conceals the infant body, and in doing so, may weaken the infant's affective ties with their parents.

Infant death continued to be seen as mundane and anticipated during the sixteenth through the eighteenth century driven by unhygienic living conditions and the widespread presence of disease and poverty (Finlay, 1981; Newton, 2014, as cited in Dycher 2019). In reaction to the fragility of the infant body, parents resisted forming emotional attachments with their young offspring, preferring instead to treat them with apathy (Aries, 1996; Pinchbeck & Hewitt, 1970; Pollock, 1983; Stone, 1979, as cited in Dycher 2019). Across social classes, parents did not spend much time with their children, instead relying on restraints like swaddling for much day-to-day supervision (Traig 2019). Examining the historical evidence, psychohistorian Smith mused:

> *"The real question is whether, since a swaddled infant can neither hug nor be hugged, an early attachment to a mothering figure can even begin to take place. Could it be the point of all these customs is to prevent such attachment?" (Smith 1984)(p64).*

Indeed, infants born into a backdrop of poverty are handled differently from those born into comfortable settings. For poor mothers, attachment is often muted and "protectively distanced" (Scheper-Hughes 1985)(p311). In her seminal paper exploring maternal detachment and infant survival in a Brazilian shantytown, Scheper-Hughes highlighted a national indifference to childhood mortality (Scheper-Hughes 1985). She detailed how experiences of attachment and separation are underscored by links between economic and maternal deprivation. For families in poverty, nurturance is impersonal and detached. This behaviour serves to shield the mother from strong emotional attachment to her infants within a culture resigned to infant mortality. "'Mother love' with its attendant emotions of *holding*, *keeping*, and *preserving* is replaced by an estranged and guarded 'watchful waiting'" [emphasis theirs](Scheper-Hughes 1985)(p312). By maintaining emotional distance, mothers are unable to see their infants as human beings and rather as inanimate objects (Piers, 1978, as cited in Scheper-Hughes 1985). Indeed, in environments that are uncertain, unstable and stress-inducing, maternal responses of ambivalence or abandonment towards their infants might aid the likelihood of survival for the mother and other, stronger children (Wren, Launer et al. 2021).

Following this ideology, the newborn inhabits a liminal space between life and death. Even today, in many societies newborns continue to perish. As well as being a practice intended to protect and strengthen babies, swaddling is a visible signal of the infant potential for becoming a corpse. In fact, the swaddled infant body resembles a little corpse or mummy, shrouded for burial. Certainly, in Turkish society, when an infant dies, they remain in their swaddling cloth which then serves as a shroud for burial (Delaney 2000).

Infant body as spiritually vulnerable

Another pervasive cross-cultural theme of infant embodiment is the perception of the infant body as spiritually vulnerable. This concept can be traced back to the European middle ages when several Christian Church Fathers suggested that, like animals, infants did not have souls. Here, the concept of *delayed* ensoulment was used to explain infants' lengthy transition to personhood (Obladen 2018). Infant liminality can be regarded as a dangerous state "because the pendulum could swing either way at any moment from the path to becoming fully human or fully other" (Dann 1999)(p64).

Aside from delayed ensoulment, two other spiritual themes emerge from the historical and ethnographic data: the fragility of the infant soul and the vulnerability to infants from evil spirits. The fragility of the infant soul is a concern of caregivers in subsistence cultures. Before three months, infants on the island of Bali are considered holy, with their spirits still belonging to the sacred realm from which they came. Perceived as visitors from that realm, they are not firmly attached to the living world. Until three months of age the infant soul has not 'stuck' to its body and is inclined to leave unless treated well (Rousseau 2017). In this vein, an ancient Indonesian custom details that an infant's feet should not touch the ground for the first 105 days after birth. Here, swaddling serves as a protective shield, binding the soul to the infant and preventing their feet from coming into contact with the earth (Rousseau 2017).

To the Balinese people (Wikan 1989, Maldonado-Duran and Lecannelier 2019) and the Karo people (Steedly 1988), keeping the infant quiet through swaddling also prevents the soul from fleeing (Broch 1990). Certainly, in communities that fear soul loss, crying is to be mitigated urgently given the belief that soul loss is more prevalent when the mouth is open (Maldonado-Duran and Lecannelier 2019, Tikkanen 2020). In Mexican culture, crying incessantly or excessively, is met with a diagnosis of 'soul lost' (Howrigan 1988). Swaddling is viewed as essential in the Mayan and the Zinanteco indigenous groups of Mexico, where it protects infants from "losing parts of their soul" (Brazelton 1972)(p94). When a Zinanteco mother arises from sitting on the floor with her infant, she brushes the floor with her *rebozo* (shawl) in order to gather possible parts of the soul that might have been left there (Brazelton, Robey et al. 1969).

In African hunter-gatherer communities, infants that cry excessively are suspected to be under the influence of evil spirits or may even be 'witches'. When this happens, the elders or a shaman may decide that the infant should be neglected (Sargent 1988). In this culture, swaddling serves an important function – it discourages excessive crying and is seen to comfort the infant. The Beng of West Africa hold the view that newborns recently emerged from a previous life and are perturbed and anxious to return to it. Within this vein, swaddling and holding the infant offers reassurance and coaxes them to remain (Gottlieb 2004)(p183). In this context, the swaddle wrap is transformed from anonymous item to a powerful spiritual artefact that enhances the likelihood of infants becoming adult members of the community.

Peruvian caretakers believe that winds, devils, and other supernatural entities can frighten people into losing their soul, a potentially fatal condition (Maldonado-Duran and Lecannelier 2019). The Quechua tribe, for instance, believe that the body houses multiple souls (*animu*) with some tribespeople maintaining that different body parts have separate *animus* (Greenway 1998). So prominent is this belief, that fright or 'soul loss' is the most frequent folk illness in the Peruvian Andes (Greenway 1998). A diagnosis of this condition can result from disjunction between interior and exterior states of being, as expressed in violent emotions, inadvertent startling, or twitching of the body during sleep (Greenway 1998). Symptoms may include disturbed sleeping patterns, loss of appetite, excessive growth of eyelashes, diarrhoea, weight loss, and listlessness (Hubí 1954). Infants are seen as extremely vulnerable, given their immaturity, physical weakness and lack of enculturation and swaddling mitigates this risk (Rojas 1970).

The ideologies of infant soul fragility and of infant vulnerability to evil spirits, work in tandem in Asian cultures. In southwest China for instance, infants are immediately wrapped from birth to protect from being claimed by the devil (Qiyao 2009), from losing their soul (Rice et al., 1994) and from "being terrified" (Liu and Ma 2015)(p75). Both ideologies are also simultaneously present in Thai Karen communities. Here, infants are swaddled as soon as possible after birth, a tradition thought to calm the newborn and protect against evil spirits (White, Carrara et al. 2012). A piece of galangal or ginger is pinned to an infant's swaddling cloth as additional protection. Focus group data of Karen midwives, explain that:

> *"If the baby is taken outside, [we swaddle] to stop the baby crying a lot; if they cry a lot the spirits will catch them. If we go out somewhere we must use ginger or galangal [aromatic roots, commonly used in cooking] to protect against bad spirits" (White, Carrara et al. 2012)(p10-11).*
>
> *"If the baby cannot move they will not feel afraid and will not have jerking of the arms" (p7).*
>
> *"If the baby cry all the time it is believed to be bothered by the bad spirit, the over crying of the baby may bring bad luck to the parents [and] can be refer to [the spirits'] wish for the death of their parents, which [is] one of the reasons why you don't want baby to cry too long and try to solve the mystery as soon as you can." (p11).*

Pertaining to the fragility of the soul, Karen people maintain that infants carry several souls and that, "the spirit[s] of the newborn baby are sensitive, [and] can be slip away from their body easily, [which is] why we must tuck [swaddle] them tightly" (White, Carrara et al. 2012)(p11). Tight swaddling is a popular imperative in other cultures mindful to protect their infants from evil spirits. Contemporary swaddling values in Kyrgyzstan maintain that, "It should keep the baby in the right place, which means tight and proper, give him a sound sleep, protect him from the evil forces, and show him the right path" (Torno 2018)(p66). Swaddling also plays a spiritually protective role in Turkish society (Katabi 2008, Geçkil, Şahin et al. 2009). For the Ifaluk people of the Caroline Islands, evil spirits take the form of *yalus*, ghostly ancestral figures who can either be evil or benevolent, depending on their past behaviour when alive; and swaddling serves as a shield against these entities (Le 2000).

Amulets and adornments are a prominent feature of swaddling for cultures seeking protection from malicious spirits. In Romania, square pieces of cloth are used for swaddling. This cloth is around two meters long and woven out of wool dyed red, yellow, and blue. At one end of the swaddle there features a compartment containing incense, a silver coin, salt, garlic, powder and three tiny metal axes. These omens are believed to protect the infant from the evil spirits (Alexin 2017). Similarly, in Iran, infants are typically swaddled in two bright cotton blankets (*qondaq*), the outer of which has amulets, shells, beads and verses from the Quaran sewn upon it (Shireen 2014). When the period of swaddling is over, it is believed that in replacement for the protection of the swaddle, the infant is now protected by 40 *benevolent* holy spirits (Pangereyev 2018).

An important factor that exacerbates infant vulnerability to spiritual evil is the perceived desirability of the infant. African hunter-gatherer communities for instance, hold a cosmological worldview in which infants are highly coveted by spirits. To combat this, parents 'fool' the spirits by making their newborns as unappealing as possible, covering their swaddle with mud and giving them derogatory names, such as "dog" or "dirt," until they are older (Gottlieb 2004). Infants are similarly coveted objects in Islamic society and particularly vulnerable to 'the evil eye' - a curse said to inflict harm on a person exposed to another's malice or jealousy (Sharma and Pandya 2017). Here, an envious gaze can release a devastating malignant power stored in the eye of the beholder. Deprivation and wistfulness can cause a person to cast the evil eye, intentionally or unintentionally. In this respect, childless women are prominent suspects, even those welcomed as familiar, such as friends, neighbours, or relatives (Qamar 2016). To delimit the desire and envy of others – the evil eye - Islamic infants are swaddled completely. In this context, the swaddle acts as an emblem that the infant is spoken for and 'covered by care' (Delaney 2000). Swaddling is conducted immediately from birth, as "prevention is preferable to prescription" (Qamar 2016)(p406).

A parallel scenario is seen in Greek culture; this country has a fertility rate (1.41 children per woman) that is well below the replacement rate (2.1) and is one of the lowest in the world (Roser, Ritchie et al. 2013). Due to their rarity, infants are perceived as vulnerable objects of desire and prone to perishing from the evil eye. Similar to Islamic culture, Greek Orthodoxy prescribes swaddling to protect from this affliction (Lipton, Steinschneider et al. 1965, Friedl and Campbell 1966). In 1960s Greek mountain communities, newborns were observed sleeping tightly swaddled in a wooden rocking cradle which is enveloped from end to end in a blanket, appearing as "a kind of dark airless tent" (Friedl and Campbell 1966)(p154).

Infant body as uncivilized

In direct contrast to adults, who are contained and controlled both emotionally and physically, infants appear as wild, uncivilized, inferior and even potentially evil (Lupton 2013). As a result, the infant requires forced containment and training in order to become civilized. Through this lens swaddling can be considered a transitional tool through which to regulate and civilize the infant body. In this respect, swaddling represents an ideology of parent-child relations in which the parent "colonizes" the child and demands that the child accept this process {Zornado, 1997 #1143}(p105). Indeed, the ancient Greeks observed that infants were "moister and hotter" than adults, which caused them to be angrier and greedier (Dann 1999)(p58). Scholars of the time maintained that infants were more like animals than humans, inhabiting a liminal existence between species (Dann 1999). Ancient Greeks expressed fear that infants would walk on all fours if they were not swaddled (Frenken 2011). Today, swaddling is often likened to an 'infant straightjacket' for their visual and practical similarities. Motivations for the invention of actual straitjackets, which occurred in the second half of the eighteenth century, echo those for swaddling through history: "Restraining the anger and violence of madmen is always necessary for preventing their hurting themselves or others" (Cullen, 1789, as cited in Majerus 2017)(p265). In appearance, the straitjacket bares functional similarities to the swaddle:

"a closed jacket, equipped with buttons or strings at the back and with long sleeves whose ends are tied to the back of the wearer. Some straitjackets also covered the head, while others immobilised the legs. Over time, smaller straitjackets materialised, such as leather gloves to restrict hand movements in order to avoid scratching, or underwear designed to prevent masturbation. Some straitjackets came with a device that secured the wearer directly to his or her bed" (Majerus 2017)(p265).

The design of the straitjacket, like the swaddle, differed depending on the amount of restraint deemed necessary (Bynum and Bynum 2016). When deploying a straitjacket it was important that caregivers "take care not to tighten the neck nor to compress the chest so as not to interfere with the [patient's] breathing" (Majerus 2017)(p266), echoing similar considerations of swaddle tightness that concern practitioners today (see Chapters 8 and 9).

Visually, swaddling was thought to produce a more human representation than what the Ancient Greeks deemed the "shrivelled animal" appearance of non-swaddled infants (Dasen 2011)(p302). In fact, through most of history, infants were of even lower rank than animals as infants were not considered to have value as property. Therefore, while it was illegal to steal objects, it was perfectly legal to steal infants. Kidnappers could only be charged with theft for the swaddling clothes the infant was wearing at the time they were snatched (Traig 2019). The ontology of infants as not only inferior humans, but even less-than-human, has been pervasive throughout history due to infants' "lack of containment of their bodies" (Lupton 2014)(p346). Certainly, swaddling renders the infant body more controllable. During ancient history, the practice masked the transitionary state between not-yet-human and human, which was believed to show in the continuous sleep of infants. Observing that young infants sleep most of the time, commentators of the era concluded that newborns must be deprived of sensations (Dasen 2011). Within this context, infants could not ‘assume human form’ unless it was forcibly imposed upon them through swaddling (Traig 2019). Perceiving swaddling as a transformative process, Anglo-Saxon infants were likened to "the chrysalis of a silk worm" (Mackarness 1861) (p247).

Infant bodies are experienced as uncivilised precisely because “[they are] what does not respect borders, positions, rules” (Kristeva, 1982, as cited in Brownlie and Sheach Leith 2011)(p203). Infant bodies are not tightly contained, controlled nor distinct from other bodies and are represented as “contaminating, grotesque and deficient” (Douglas, 1980/1966; Turner, 2003, as cited in Lupton 2014)(p348). In this vein, corporeal dimensions of infant-care involving the production, elimination and control of body products - urine and faeces - are shielded by the swaddle and treated as a private matter (Conklin and Morgan 1996).

Contemporary European discourse is perforated with a view of infants as inherently unregulated and unsocialised, requiring adults' close surveillance and control (Lupton 2014). In Turkey and Romania, swaddling in seen to protect infants from ‘dangerous movements’ (Okka, Durduran et al. 2016). A common assumption maintains that "the baby has to be tied up or it will tear its ears off, scratch its eyes out, break its legs, or touch its genitals" (deMause 2005)(P11). That uncivilised infant bodies are unable to protect themselves is not a recent realization; Soranus recommended that swaddling would prevent infants from self-injury, for example, ruining their eyesight by rubbing their eyes (Soranus and Huber 1894, Frenken 2011, Bell 2013).

Infant body as sinful

In some cultures, the requirement for 'protection from self' rests on the assumption that infant character is inherently malevolent and therefore the infant body needs to be tied up tightly for long periods (Haffter 1968)(p61). In the popular seventeenth century play King Lear, William Shakespeare likened infants confined by tight swaddling bands to the punishing experience of being trapped in ‘stocks’ (Harris Williams 2011). This equation of the infant body as sinful is thought to stem from the advent of Calvinism and Protestantism in the European middle-ages. During the early centuries of the church, the theology of original sin imputed the guilt of Adam’s first sin to infants (Beach 2001). This prompted a shift in adult focus towards repressing infants’ natural impulses (Calhoun, 1945, as cited in Ilias and Akter 2017). Without such intervention, it was believed that infants would be sent to hell if they died (Stearns 2015).

The belief in the sinful infant body carried through to the early modern period with records showing popularity amongst American Puritans (1630–1640). Indeed, the term Puritan means ‘against pleasure’ and in this view, an infant’s natural impulse to play was considered sinful (Mintz 2006). A moral preoccupation with the rational mind over the pleasure-seeking body (Bordo 1993, Turner 1984, as cited in Conklin and Morgan 1996) positioned infants as deviant sexual beings (Frenken 2011). A parent's role was therefore to provide strict training to help the infant resist their satanic temptations (Reese 2000). This doctrine led seventeenth- and eighteenth-century parents to seek methods of breaking down the child's will (Dycher 2019), with swaddling proving popular (Frenken 2011). When observing historical swaddling practices, Zornado posited that "if swaddling offered as one of its chief aims physical restraint, along with this went the desire to restrain the child morally and emotionally" (Zornado 1997)(p106). In this vein, swaddling has been described as a method of "preverbal indoctrination" (Lipton, Steinschneider et al. 1965)(p532).

The practice of swaddling addresses the problematic state of infancy, demarcating acceptable infant behaviour. In the 1940s for instance, Polish parents were noted to believe that swaddling prevents clean and dirty body parts from touching. Feet are considered particularly dirty. Within this belief system, swaddling prevents an infant from placing their feet in their mouth, as infants are naturally inclined to do. Such shame-ridden are feet in Poland, that when the infant is unswaddled for bathing or nappy changing, careful effort is given to ensure the feet do not touch other areas of the body (Benedict 1949). Similarly, in Romania, swaddling is considered essential to prevent the dangers of masturbation (Coolidge, 1905, as cited in Wright 1987) whereas in Russia, it is tradition for infants to be swaddled in their father's dirty shirt in the hope that his positive personality characteristics will transfer to the infant and override their sinful ones (Rouhier-Willoughby 2003). These European exemplars illustrate the ways in which swaddling moulds and trains the infant "so that when they eventually shed their physical otherness, they will shed their social otherness as well" (Dann 1999)(p68).

Swaddling is also a training instrument within Chinese culture. Chinese parents maintain that restriction of the body moulds the infant's character and behaviours, and if wrapped properly, their offspring will not end up doing evil things (Liu and Ma 2015). Swaddling in China has a long history dating back to the Shang Dynasty (Liu and Ma 2015). Considered a parent's 'first gift to the child', swaddling supports Confucian teachings that suggest the external environment has biggest substantial impact on the developing child (Wu 1996). Here, swaddling is a part of *chiao shun*, an authoritarian style of parenting which means 'child training' (Chao 1994, Raj and Raval 2013), and *filial piety*, which means to 'respect one's parents' (Lee 2017). These ideologies dominate Chinese parenting and provide the ultimate goal of raising a child with "control and governance" (Chao 1994)(p1113), whose identity is rooted within the family (Lo 2016).

Swaddling and body boundaries – proximal and distal care

One cannot discuss the embodiment of infants without examining their inter-embodiment with mothers. As is discussed in Chapter 4: Biobehavioural Review, infants and mothers form a co-relational dyad fuelled by oxytocin-dependent affiliation networks (Meaney 2010, Feldman 2012). Just as the social meanings given to infant bodies transform how caregivers handle infants, so they create and transform the mother-infant relationship.

The bodies of mother and infant are experienced relationally as each reacts to the other. The over-lapping, transactional nature of this relationship is felt through numerous channels including touch and movement. Is swaddling therefore a physical and proprioceptive boundary between mother and infant? On the contrary, in some cultures swaddling *facilitates* this interembodied relationship. In Chinese culture, the very act of tying the swaddle is thought to symbolise connection with family (Qiyao 2009). In hunter-gatherer groups, like the Beng of West Africa and the Gusii of East Africa, swaddling turns infants into a mobile unit and in turn, facilitates a high degree of holding and carrying of the infant, not only by mothers but by other kin also. At three to six months of age, Gusii infants are held 80 percent of the time (Richman, Miller et al. 1988), whilst Beng infants are passed to different people 7 to 8 times per hour, and are held by 7 to 14 different individuals during an 8-hour period (Tronick, Morelli et al. 1987). Through this lens, swaddling is viewed as a "moving bed" (Gottlieb 2004)(p179).

Within the Peruvian mountain region, swaddling serves a similar utility. In this oftentimes freezing climate, Peruvian mothers adopt a configuration known as 'the manta pouch'. Here, the fully dressed infant is tightly swaddled in several blankets with their arms positioned at their sides, and then placed in a carrying blanket which is then positioned on the mother's back. Described as "a hospitable and portable micro-environment for the young child" (Tronick, Thomas et al. 1994)(p143), this practice unites mother and infant as one mobile unit "as though the infant is not yet born" (Whiting 1981)(p174).

The above examples demonstrate what anthropologists term 'proximal infant-care' (Keller and Otto 2009, Keller, Hentschel et al. 2016). Proximal customs are characterized by bodily proximity and body stimulation. They can be understood as distinct from 'distal infant-care' which is characterized by communication through the distant senses (Keller and Otto 2009, Keller, Hentschel et al. 2016). Middle-class Euro-American parents engage in caregiving customs that are primarily distal (Lachin and Schachter 1974, Keller 2003, Lo 2016, Little, Legare et al. 2018). Cots, swings, prams, and bouncers, are all examples of distal customs where the infant's daily routine involves spending time in various 'containers' (Keller, KÄrtner et al. 2005, Keller 2013, Keller, Borke et al. 2016, Keller, Hentschel et al. 2016, Keller and Lamm 2016, Little, Legare et al. 2018). These practices emphasize autonomy and separateness and limit physical contact between infant and caregiver, they are *individualistic*. Swaddling can also be considered a distal container when applied for separative purposes. For instance, the ancient Greeks engaged in distal care through swaddling, informed by the belief that the proximity of the mother to the child could actually attract the envy of child-killing demons and the wrath of the gods onto her child (Dann 1999).

If applied for distal care, the swaddle wrap functions as both a transitional object and a performative object in the conventional sense of the terms (Lupton 2013). It is a 'substitute for mother' and a socialisation tool to guide infants through the process of realization that their mother is a separate person whom they do not control (Winnicott 1966, 1971, 1958, as cited in Ross 1982). In contemporary India for instance, swaddling is seen to mirror the 'containing' functions of the mother, and to contribute to the 'cultural containment' of the infant (Stork 1986, Mellier 2010). Further, in Uzbekistan, where carrying infants is thought to make them irritable, the Uzbekistani ability to control emotions has been attributed to the swaddling. Indeed, "the child who lay in a swaddle much time will be quiet, gentle and meek" (Mashrabjonovna 2006).

Perhaps the most formidable example of distal care is given by the ritual of 'the Kurdistani cradle'. In Kurdistan Iraq, the inability to perform nappy changes during swaddling led parents to adopt a novel technique. First, the infant trunk is firmly swaddled using strips of cloth with arms by the side; Next, the buttocks are exposed over an open pot and a set of reeds placed over the genitals. Depending on the sex of the infant, a flute or tube is placed between the legs of the infant to collect urine. Additional cloths are positioned over the chest and legs and then around the cradle. The majority of cradles are designed to be low to the ground and covered with a hood to ensure a dark sleeping environment. Demonstrating various degrees of opulence, the cradles have been made of fruit tree wood and usually decorated with colourful tassels and trinkets (Bloch 1966).

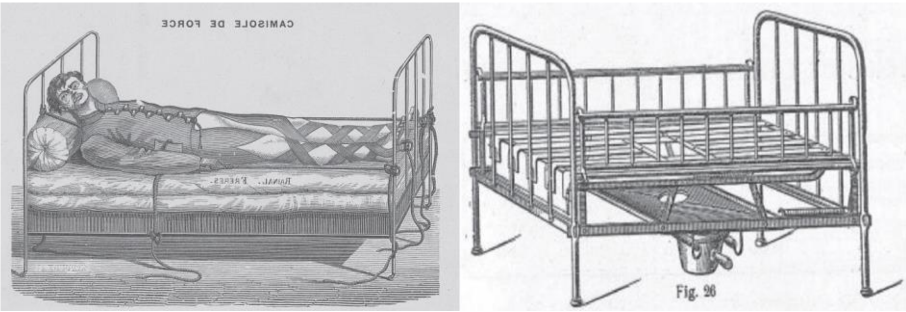
Figure 3 The Kurdistani cradle

This swaddle technique eliminated the requirement for nappies and therefore eliminated instances of nappy rash. Infants typically stay in the Kurdistani cradle until their next sibling is born, usually around 18 months (Bloch 1966). This portable 'metabolic bed' (Fomon, Thomas et al. 1962) enabled parents to visualise their infants but remain unencumbered by infant care demands:

> *"As soon as he comes home from the maternity hospital the new infant is strapped into the cradle. He is not removed even for breastfeeding, since this can be carried out by the mother bending down. If he cries for causes other than hunger, she can rock the cradle"* (Bloch 1966)(p641).

The Kurdistani cradle bares striking similarities to the eighteenth century ‘straitjacket bed’ wherein psychiatric patients were strapped to a hospital bed and permitted to defecate through a hole in the bed and into an awaiting bucket, as illustrated in Figure 4.

Figure 4 Straitjacket bed of the eighteenth century (Majerus 2017).



The Kurdistani cradle is a common feature of infant-care in all five of the post-Soviet countries of Kyrgyzstan, Kazakhstan, Uzbekistan, Tajikistan, and Turkmenistan (Mashrabjonovna 2019, Zaxlacki and Derrick 2020). In Kyrgyzstan, the cradle is referred to as *beshik* and thought to serve "as an intermediate space between the mother’s womb and the house as well as between the cosmic and social domains before the child starts to crawl inside the room and walk outside on the street" (Torno 2018)(p21). The covers of the cradle are changed depending on seasons, with cotton used in summer and velvet preferred in winter (Mashrabjonovna 2019). In Kyrgz culture, it is customary for older women to conduct "the rite of first swaddling" (Zaxlacki and Derrick 2020) (p65). This happens with great celebration and ceremony when the infant is 40 days old. Beginning with a feast called *beshik toi* (Torno 2018), the ritual finishes with a presentation of the child, during which guests endow the family with gifts (Advantour 2018). Although increased levels of household education and urbanization are inversely related with beshik usage, in the minds of Kyrgyz people, the beshik is synonymous with swaddling, and parents seldom engage in one practice without the other (Zaxlacki and Derrick 2020). Rural communities in Kyrgyzstan have continued to use the beshik long after abandoning the nomadic lifestyle for which the device was intended.

In Tajikistan the *beshik* cradle is known as ‘the gahvora’ and is a treasured gift passed down from generation to generation. In this culture children are adored and the centre of family life. Tajik infants are rarely seen to protest as they are swaddled, bound and catheterized for the *gahvora* (Karasik, Tamis-LeMonda et al. 2018). They spend up to 20 hours per day strapped into the device (Save the Children 2011), during which their caregivers respond immediately to their vocalizations by feeding, rocking, or singing (Karasik, Tamis-LeMonda et al. 2018). Older children and members of the community frequent the cradle to interact with the infant. The high rates of responsiveness given by Tajik caretakers whilst their infants are strapped into *the gahvora* cradle reflect a conceptualisation of infants as fully actualised persons who belong in the midst of social culture. Herein lies a curious example of how, in specific circumstances, swaddling can straddle the boundaries of proximal and distal care.

Socialisation: individualism and inter-dependence

Proximal and distal caregiving styles are thought to be practiced in differing ratios across cultures. Societies that engage in high amounts of body contact show low amounts of mutual visual engagement and vice versa (Keller, Lohaus et al. 2004, LeVine 2004, Keller 2013). Proximal customs predominate in societies with socialization goals that embody relatedness, obedience, and hierarchy (Keller, KÄrtner et al. 2005, Keller and Lamm 2016). Communities with hunting, gathering, and agriculture economies typify this caregiving style (Keller, Lohaus et al. 2004). The practice of swaddling in conjunction with co-sleeping may be viewed as proximal care. Yet this approach would be criticised as irresponsible and dangerous by contemporary Western caregivers, who are predominantly distal in their caregiving (Ball 2007).

Interestingly, western society was not always ideologically distal. In the mid-twentieth century the popularity of distal care dropped dramatically due to an economic and political shockwave - the advent of attachment theory. The central tenet of this theory was that infants needed to develop a close relationship with a responsive mother to ensure normal social and emotional development. Accordingly, any degree of mother–child separation posed a danger to the child. The theory capitalised upon the politically conservative mood of the time, and in the aftermath of the Second World War, became very much in vogue. Up until this point, swaddling provided a mode of *de*tachment, decoupling infant-care from the maternal body. In contrast, attachment theory was radical in that it emphasised the importance of a *proximal* mother-child bond (Harlow 1959, Ainsworth 1969, Bowlby 1969, Ainsworth, Blehar et al. 1978).

Nonetheless, despite the persistent popularity of attachment theory, contemporary Western societies continue to swaddle and to perform a predominantly a distal approach to infant-care. Why might this be? The answer is both ideological and political. Performance of distal care can spring from the challenges of interembodiment, in particular dealing with the uncivilized infant body (Lupton 2013)(p38). The infant body is demanding and disruptive in the sense that it disrupts bodily boundaries and is a threat to order and control (Lupton 2012). In Western society, the infant body is interpreted as encroaching on the prized ideals of self-autonomy and individualisation (McKenna, Ball et al. 2007). These ideals form the dominant model of personhood in that culture. Indeed, personhood is both a dynamic social category and the product of cultural practice. Cultural conceptions of personhood range along a continuum from extreme individualism to extreme inter-dependence (Geertz 1975, Lonner, Berry et al. 1980, Triandis, McCusker et al. 1990, Conklin and Morgan 1996, Fiske, Kitayama et al. 1998, Keller 2002, Morling and Lamoreaux 2008, Oosterman and Schuengel 2008).

An independence-promoting orientation is evident in societies such as the USA and those with a strong Euro-American influence whose inhabitants gravitate towards individualistic ways of thinking. It is estimated that 90% of infants in the USA are swaddled during the first few months of life (Oden, Powell et al. 2012). In a country where there are 'hot lines' for parents to call for support to deal with their infant's crying (Maldonado-Duran and Lecannelier 2019), and where parents deliberately refrain from responding to their infants crying (Bell and Ainsworth 1972, Hubbard and van Ijzendoorn 1991), American parenting is dominated by the ideals of psychological independence, self-control and self-reliance (Ball and Russell 2012). Even before birth, a motivational gravitation towards independence begins with the ritual creation of a separate room for sleeping - 'the nursery'. Valuing separation and minimal bodily contact (Ball 2008, Ball 2012, Ball and Russell 2012, Trevathan and Rosenberg 2016), in this culture young infants are held and/or touched only 12 to 20 percent (2 to 3 hours) of waking hours and older infants are held and/or touched less than 10 percent of the time (Bernal 1972, Tulkin 1977, Hunziker and Barr 1986). By four months old, American infants spend around 40 percent of their waking day in 'containers' such as highchairs, bouncers, seats, and playpens (Richman, Miller et al. 1988). Parents within individualistic cultures have been described as "encouraging their children to develop into independent, autonomous individuals who have fragile social ties to the larger group" (Tamis-LeMonda, Way et al. 2007)(p185). Swaddling reflects these values by reducing an infant's reliance on others and restricting communication. In essence, swaddling imposes a critique of the infant body as asocial, in that social interactions are irrelevant to the swaddled infant body. The practice trains infants to rely less on their mothers for comfort and containment, to demand less, and hopefully to ‘sleep through the night’ [4](Tomori 2014). Indeed, interventions like swaddling are seen as particularly useful for the 25-30% of American parents who report their child has a 'sleep problem' (Mindell, Kuhn et al. 2006, Mindell, Sadeh et al. 2010). For this population, proximal parenting is strictly condemned by the argument that caregivers would get “entangled in the sleeping practices of their child” and their child would not develop the independence necessary to fall asleep by itself (van Sleuwen, L'Hoir M et al. 2006)(p512). Certainly, when used routinely, swaddling disciplines the infant body towards habits of sleeping and feeding that are more culturally acceptable. For parents, it brings order to perceived chaos. "It is in sleep that the infant is least demanding" (Lupton 2014)(p343).

In contrast to the independent stance of post-industrial countries, less industrialised communities such as Native Americans or the Peruvian Quechua are deemed ‘interdependent’ in nature, given that cooperation among individuals is crucial for their survival. Within these settings, swaddling, as a portable and versatile tool, facilitates caregiving by multiple people of both sexes and various ages (Hewlett 1996). Dwellings in interdependent cultures are more likely to house large families. In turn, these families are more inclined to swaddle so that caregiver resources can more equitably stretch between

[4] ..a term, the definition of which, varies as widely as the sleep duration it seeks to describe Henderson, J. M., G. Motoi and N. M. Blampied (2013). "Sleeping through the night: a community survey of parents' opinions about and expectations of infant sleep consolidation." J Paediatr Child Health **49**(7): 535-540.

numerous recipients (Li, Liu et al. 2000, Mashrabjonovna 2006). How are caregiver resources managed and distributed in individualistic cultures? The answer is, not without conflict.

Parent-infant conflict - tension between productive versus reproductive labour

> *"I am tied. I want to free my hands but I cannot do it, and I am crying, weeping, and my cry is unpleasant to me, but I cannot stop... I want freedom, it doesn't hurt anybody, and, I, who need so much, I am weak and they are strong"*
>
> (Tolstoy, 1913, as cited in Lipton, Steinschneider et al. 1965)(p532).

Here, Tolstoy wrote of his 'first recollections' of swaddling, which were characterised by conflict with his caregiver. The scene reflects the evolutionary paradigm of parent–offspring conflict. This paradigm recognises that infants are naturally inclined to seek more parental resources than is in the caregiver's best interest to provide (Trivers 1974, Stuebe and Tully 2019). In Europe, this conflict was stoked by changing social niches. Beginning in the European middle ages, economic shifts from subsistence agriculture to commerce and later to industrialisation resulted in an ideological reshaping of reproductive lives. Parent-offspring conflict was highly influenced by the nexus of power/powerlessness that signified maternity at the time. The medieval patriarchal emphasis on nature, function and hierarchy, combined with a dogmatic acceptance of the divine plan doctrine, created a culture obsessed with comparative rankings, with infants placed at the very bottom (Traig 2019). Historians typify this era as having little concern for children between birth and five or six years old (Hughes 2008), with both men and women showing a "resigned acceptance of children" (Lyon 2017, para. 2).

Indeed, after the industrial revolution (1760-1840), children were no longer seen as economic contributors but instead as costly liabilities (Stearns 2015, Ilias and Akter 2017). Growing industrialization and the dominance of capitalist economic system created a new child-rearing dilemma - the imperative to get infants to 'sleep through the night' (Tomori 2014). Prolonged and independent monophasic sleep became the hallmark of a 'good baby' (Ball and Russell 2012). Until the invention of artificial light in the nineteenth century, human sleep had always been segmented (Ekirch, 2013, as cited in Traig 2019). Infants in particular have a polyphasic sleep pattern which late modern authors asserted could be remedied by swaddling.

> *"When enveloped in the steady pressure of a light and porous shawl, so that, like Wordsworth's cloud "it moveth altogether, if it move at all," many a restless infant will fall soundly asleep"* (Cameron 1931)(p241).

As the advent of industrialisation required (working class) women to work in factories, swaddling became associated with gross neglect. It was common practice to send infants out to wet-nurses. Reports suggest the nurses swaddled infants and then failed to wash or comfort them for long periods of time (DeMause 2002). Life became a struggle, not between the 'strong and the weak' as Tolstoy phrased it, but between "the weak and weaker" (Scheper-Hughes 1985)(p303).

Because of the commonality of sending infants to wet-nurses, time between pregnancies was brief, and it was not uncommon for families of the era to have twelve to fifteen children. Parents that couldn't afford a wet-nurse would hang their swaddled infants on pegs whilst they worked nearby (Fontanel and d'Harcourt 1997). Pacified, immobilised infants enabled caregivers to work and to transport their infants easily (Stearns 2016). Some swaddled infants were strapped to carrying boards similar to those used by American Indians (Hartley, 1931, as cited in Lipton, Steinschneider et al. 1965), others were swaddled and placed in a cradle (Mintz, 2004, as cited in Traig 2019). Historians note that it was considered acceptable and proper to leave an infant alone in a cradle while the mother worked providing the infant was swaddled. Swaddling kept infants from flailing around and falling out of their cradles, a documented problem of the time (Stirler 2013). In essence, swaddling allowed parents (mothers) to prioritise productive over reproductive work.

A similarly detached approach to child-rearing was seen in the early modern period, described as loveless and antagonistic to the welfare of the child (Badinter, 1981, as cited in Wilson 1984). Records speak of infants stewing in their own excrement for hours on end, tightly wound in swaddling clothes, left unattended by fireplaces. Such horrors were lamented by Rousseau's, worth quoting in full:

> *"Ever since mothers, despising their first duty, have no longer wished to nurse their children, it has been necessary to entrust them to hired women, who, finding themselves thus mothers of strange children for whom nature said nothing to them, have sought only to spare themselves trouble. It would be necessary to watch ceaselessly over a child at liberty; but, she tosses him in when is well bound, a corner without bothering about his cries. These sweet mothers, who, rid of their children, gaily give themselves up to the amusements of the town, do they know, however, what treatment the child in swaddling clothes receives in the village? At the least annoyance which arises, he is hung from a nail like a bundle of old clothes; and while, without hurrying, the nurse attends to her business, the unfortunate one remains thus crucified"* (Rousseau, 1762, as cited in Lipton, Steinschneider et al. 1965).

The conflict between reproductive and productive labour continues today. It thus is an unfortunate paradox that, by delimiting infant agency through motor restraint, swaddling may not be consistent with the Western goal of socializing children to be self-directing, a virtue of productive work. In this context, the custom of swaddling may indicate a trade-off between Western parental desire to stimulate infant development and a conflicting Western desire to meet one's own individual needs (Tully and Ball 2013). This stance is driven by the need to thrive in modern and postmodern information-based societies in which individual performance and competition underpin success (Keller, Hentschel et al. 2016). An ideological artifact of information-based societies, (some may say information-*saturated* societies), is the cult of 'scientific motherhood'.

Biomedicalisation and scientific motherhood

> *"Maternal instinct left alone succeeds in killing a large proportion of the babies born into this world" (Apple 1995)(p167).*

This authoritarian quote originates from a 1911 issue of *Good Housekeeping*. The early 20th century saw a boom in such infant-care literature. Here, infant behaviours such as excessive crying were problematised and blamed on maternal ignorance (Wright 1987). Relatedly, swaddling harmonised with the advice of physicians and academics who advocated a detached and authoritarian mode of infant-care that discouraged the infant from becoming 'too' bonded to their caregivers. In this context, parents were advised to ignore infant wants and to focus on the physical and mental engineering of the child (Watson, 1928, as cited in Dycher 2019).

During this period, Europe saw a transformation in the concept of infancy driven by a realisation that mass infant death was not inevitable; Rather, it could be mitigated by medical intervention and instruction. Infant care, which had hereto been a moral endeavour policed solely by mothers, was coveted by the medical elite and healthy infants became a societal imperative (Wright 1987, Apple 1995). The scenario introduced a paradoxical dynamic. It positioned mothers as both responsible for infant-care and incapable of that responsibility (Apple 1995). The new "medical gaze" denigrated maternal instinct and experience, whilst reinforcing the dominant Western ideology of infant bodies as discrete, asocial biological bundles to be managed (Wright 1987)(p109). The era saw the development of 'scientific motherhood', the belief that women require authoritative scientific and medical advice to raise their children (Hardyment 1983, Hulbert 2011). In academia, methodical research engaged in the pursuit of ideal developmental outcomes for children (Traig 2019), giving birth to "a swarm of patronising advice manuals" (Dycher 2019)(P24).

The medicalization of childbirth and the academic codification and canonization of child development complimented the emergence of industrialization and a capitalist economic system (Hardyment 1983). These combined factors nourished a biomedicalization of infant sleep in which normal variations were problematized and pathologized (Wolf-Meyer 2012). By the 1950 and 1960s, this agenda was reinforced by individualistic discourse emphasising the virtues of psychological independence, self-control and self-reliance popularised by 'experts' such as Freud and Skinner (Ball and Russell 2012). Grounded in operant theory, dominant advice involved delaying one's response to infant communication efforts, a 'cruel to be kind' process that was thought to foster independence and build "infant sleep resilience" (Ball, Douglas et al. 2018)(p522). One of many parenting advice manuals of the time maintained that “obedience in infancy is the foundation of all later powers of self-control” (King, 1945, as cited in Dycher 2019)(p33). The appropriateness of this 'hands-off' approach was assured by the advice of paediatricians that infants should 'sleep through the night' by 3 months of age (Crichton and Symon 2016, Kempler, Sharpe et al. 2016, Middlemiss, Stevens et al. 2017). Demands for a hands-off 'intervention' combined with an ideology that discouraged touching and cuddling, created a culture that was enthusiastically receptive to swaddling. The practice dutifully forced obedience upon infants whilst regulating feeding and sleeping (Dycher 2019). Bottle-fed solitary sleeping infants became the revered norm (Ball, Tomori et al. 2019), producing a cultural "cult of independence" (Valentin 2005)(p269). Emphasis was placed on regular daily routines with established sleep schedules that coordinate with parental employment needs (Harkness, Super et al. 2007). Within this zeitgeist was the expectation that infants should develop consolidated sleep, a political artifact necessitated by an overwhelmingly industrialised environment (Ball and Russell 2012, Hinde 2014, Ball, Tomori et al. 2019).

Against this backdrop, contemporary health professionals maintain borderline celebrity status in industrialised Western culture and their views revered (Margalit 2018). Here, scientific motherhood is used to promote specific infant-care approaches and associated merchandise (Apple 1995). Within this market, recent technological advancement has given rise to the development of products that enable continuous health monitoring of infants, such as swaddle blankets that record breathing, temperature and body position, sending this data to parents' smartphones (Sense-U 2018, Memon, Memon et al. 2019). In this vein, the individualistic values of Western society compliment an emerging 'sleep industry' that positions swaddling as a "another weapon in competitive parenting" (Green 2020)(p1).

The germ pathogen theory

One consequence of "the annexation of infant welfare to medicine" (Wright 1987)(p112) was the biomedical preoccupation with separation of bodies to ensure 'safety' (Alexeyeff 2013, Tomori 2014, Tomori, Palmquist et al. 2016, Ball, Tomori et al. 2019). The early 20th century saw a major shift in the philosophy of infant-care advice. Concern focused on the issue of boundaries – or lack of them – between infant bodies and pathogens. Western discourses presented infant bodies as highly permeable, open to contamination by outside pollutants (Lupton 2014). This concern was known as 'the germ pathogen theory' and quickly became the dominant model of causation for infant mortality; it's popularity served to further legitimise medical expertise (Wright 1987). Germ pathogen theory created a desire to protect the inside of the infant body from the potentially contaminating external environment. In doing so, it highlighted an ontology of body boundaries. Here, the environment is considered to pose a threat to the vulnerable under-developed infant, and "their permeable body boundaries must subsequently be guarded and protected" (Lupton 2013)(p44). In this vein, a hygiene textbook, *Fighting Dirt: the World's Greatest Warfare,* perceived of the child body as "a great fortress" around which "deadly enemies surround them, lurk in their clothes, cling to their flesh" (Hood, 1916, as cited in Wright 1987)(p119). Swaddling, which was already popular as a distal care practice, became a protective boundary prohibiting infants from touching dirty objects.

Interestingly, cross-cultural data echo behaviour suggestive of germ pathogen theory and the associated need for boundary monitoring and maintenance. Brazilian mothers have cited fear of "strong germs that enter through the fingernails" (Scheper-Hughes 1985)(p306). Further, southern California's Spanish-speaking communities believe that air containing elements dangerous to health - *malaire* (bad air) - can enter the body through uncovered openings. This bad air is regarded as a frequent cause of illness and cool air is considered particularly harmful (Zepeda 1982). Saudi Arabian parents are similarly motivated to swaddle their infants to protect "from air" (Lamadah 2013)(p845).

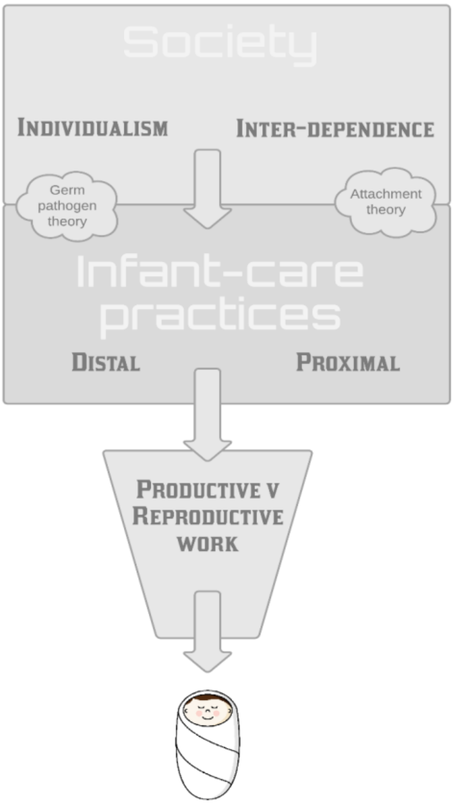
Conclusion

This review has furthered infant-care discourse, positioning swaddling as a universal practice implemented in culturally specific ways. The fact that swaddling is practiced in all inhabited global continents is interesting and may reflect something inherent in the practice that resonates with all parents. Indeed, examination of interventions applied at the start of life, such as swaddling, provide a window into wider cultural beliefs about the nature and nurturing of infants. Several anthropological paradigms have facilitated this cross-cultural, cross-historical interrogation. Firstly, the sociohistorical constructs of infancy, embodiment, and personhood were revealed as interwoven. The review explored how perceptions of infant personhood are often contingent on the social meanings given to their newly developing bodies. Ontological differences between infant bodies and other members of the species: older children and adults, make infant personhood precarious. Within a context of the infant body as Other - uncivilised, annoying, lacking self-control - swaddling is both a symbol of liminality and a mitigative response. Swaddling attenuates the dangers associated with liminality: disease, death, demonic attack, malformation, self-injury, emotional attachment. Constructs such as soul loss, fright illness, or the celebration of *shldekhana*, demonstrate the cultural construction of infant bodily identity for which the act of swaddling becomes a metaphor. Through this lens, issues of body boundaries come to the fore. Here, cross-cultural ideological differences reveal swaddling being used to emphasize individual autonomy, as in the asocial and distal Western infant, or social kinship, as in the proximal Wari infant bound to its mother's body.

Factors such as institutionalized employment schedules filter into parental expectations of infant behaviour (Sadeh, Tikotzky et al. 2010) producing and reproducing the dichotomous ideologies of individualism and interdependence. Such narratives demonstrated how social conditions play an instrumental role in constructing the social and cultural response to infancy. Just as swaddling manipulates the dynamic of communication between parent and child, the infant body provides a theoretical map against which ideological battles – between the weak and the weaker - are fought. Motivations for swaddling represent broader transcultural understandings of infant health and illness. Through the medium of swaddling, the immediate, often conflicting, concerns and perspectives of mothers, infants, and professionals are illuminated.

This review is the first to link several anthropological concepts into a synthesised network (Figure 5). The embodiment of infants and their interembodiment with their mothers is performed through the dichotomy of proximal and distal care. These infant-care styles are influenced by dominant ideologies of socialisation – inter-dependence versus individualism, with the former favouring proximal care and the latter favouring distal care. Within this vein, metaphors that transform the infant body into socially meaningful forms expose systems of power and hierarchy, and of economic (industrialisation, capitalism) and political (patriarchal biomedicalisation) forces. Beliefs regarding the nature and needs of infants, parenting, and the family, produce and reproduce these cultural agendas which, in turn, shape caretaking practices (Harkness and Super 1996).

Figure 5 Synthesis of anthropological paradigms



Although many of the anthological paradigms developed to understand cultural difference are classically presented as dichotomous, this review has revealed considerable dynamic variability within cultural groups, mediated by factors such as socioeconomic class, urbanisation, and climate. Further, whilst cross-cultural and cross-historical contrasts are evident, the review has underscored that individual members of a society are not passive consumers of their society's dominant ideology; rather, they invoke different ideologies to suit different purposes (Conklin and Morgan 1996). The presented overarching framework augments an understanding of infant-care through which swaddling is applied in a non-arbitrary manner as part of a cultural system. Within this system, swaddling is shown as a functional and symbolic vehicle through which cultural values, rules, and standards are transmitted. It is a “moving bed” (West Africa), a “house” (Wilson, Taylor et al. 1994), a “shroud” (Turkey), and an “artificial skin” (Indonesia). It is an adaption to cultural ideologies and practices, whether individualistic and distal, or inter-dependent and proximal.

Chapter 4. Swaddling: a biobehavioural review

> *"The swaddled baby lies still with its eyes closed, and is believed to be sleeping"*
> *(Bergman 2014)*

This quote highlights the intersection between the behavioural (the baby appears to be sleeping) and the biological (but are they neurologically asleep?) The conceptual issues that arise from this observation and the methodological challenges they present could be usefully addressed by a biobehavioural approach. Here, the thesis moves from the macro scale (evolutionary, sociohistorical) to the micro-level of how swaddling directly affects the infant's biology and behaviour. By synthesising observational and epidemiological literature, the aim of this review is to understand the mechanisms involved in the production of swaddle outcomes. This will be achieved through a three-tier approach. The review examines swaddling within biological systems (respiratory, nervous, thermoregulatory), behavioural phenomena (arousal, sleep, feeding), and developmental fields (cognitive, social, physical). Discussions of each will vary in length, owing to the degree of available literature.

Part One: Swaddling and Sleep

> *"Swaddling 'works' because it forces the baby to sleep"*
> *(Frenken 2011)(p90).*

Recent medical scholars define sleep as "a time of enhanced neurological function and physiologic activity" (De Beritto 2020)(p82). As an external regulator of infant sleep, swaddling may evidence the role played by sleep ecology in the development of infant sleep rhythms. Yet despite over 50 years of infant sleep research, only a handful of studies have investigated the intervention using healthy term infants (see Table 1) and their findings are inconclusive. Some data show that when swaddled, infants sleep between 38 and 46 minutes more per day (at 6 and 12 weeks, respectively) (Manaseki-Holland, Spier et al. 2010). In one clinical study (Richardson, Walker et al. 2010) swaddling did not prolong sleep duration at 3 to 4 weeks age but however *did* at 3 months. Further, when data is restricted to routinely swaddled infants, no significant changes in sleep length and arousal between swaddled and unswaddled states have been found (Kelmanson 2012).

Table 1 Overview of sleep duration swaddle studies

Studies associating swaddling with increased sleep duration	**Studies associating swaddling with no effect on sleep duration**
(Lipton, Steinschneider et al. 1965)	(McRury 2010)
(Caglayan, Yaprak et al. 1991)	(Kelmanson 2012)
(Franco, Seret et al. 2005)	
(Manaseki-Holland 2010)	
(Meyer and Erler 2011)	

In their study of 101 British infants St James-Roberts and colleagues found that developmental progression in sleep length was accompanied by an increased use of sucking on hands or fingers; Those infants with the longest sleep periods used this self-soothing or self-regulatory strategy more than those with shorter sleep periods (St James-Roberts, Roberts et al. 2015). Swaddling is paradoxical in that it prohibits those behaviours "developed by an individual to manage his or her arousal as opposed to external regulation provided by caregivers and other parts of the environment" (St James-Roberts, Roberts et al. 2015)(p325). If applied routinely as advised, swaddling may become a 'sleep association', prohibiting infants from engaging in instinctive self-soothing behaviours such as hand-sucking. Sleep associations created through use of interventions such as swaddling are shown to predict parental report of persistent sleep problems one year on (Morrell and Cortina-Borja 2002).

The effect of an infant's ecology on their sleep-wake patterns illuminates numerous deficits in research methodologies to date. A prominent example is the failure of swaddle studies to account for infant feeding mode. A 2015 systematic review of swaddling revealed that the majority of studies failed to account for this variable (Dixley 2015), despite the fact, widely recognised by bioanthropologists, that breastfed infants do not experience lengthening and consolidation of nocturnal sleep as early as their formula-fed peers (Carey 1975) (Ball and Russell 2012). Another methodological gap is mode of delivery, a widely neglected ecological variable that is associated with differences in wakefulness, sleep duration and length of active sleep (Freudigman and Thoman 1998).

In addition to ecological factors, sleep is influenced by internal physiological processes, such as respiration, heart rate and muscle activity (Prechtl 1977, Rainforth 1982). These dynamic organizing and control systems cluster and are manifested in behavioural 'states' (Ashton 1976) such as crying, active awake, quiet awake, etc. Recognizing infant states is thought to be the single most important element for understanding an infant's response to the environment (NCAST 1990, White and Bryan 2002) and an integral part of appreciating early developmental processes (Goff 1984). In this context, swaddling is thought to 'help' infants move from a higher to a lower state (e.g., crying to quiet alert or active alert to sleep) (White and Bryan 2002).

Two important states in the infant sleep repertoire are 'active sleep' (AS) known as Rapid Eye Movement sleep in adults, and 'quiet sleep' (QS). During sleep, infants pass through periods when the brain is active and processing information (AS) and periods when the brain is quiet and restorative (QS). Normally, it is much easier to be awakened during AS than QS, yet when swaddled, infants experience an overall decrease in arousability, even during AS (Czikk, Sweeley et al. 2003, Richardson, Walker et al. 2010).

Oscillation between AS and QS is known as a 'sleep cycle'. On average, infants' sleep cycles are 60 minutes long, and are mostly composed of AS (Anders 1974, Peirano and Algarin 2007, BASIS 2020). During their first year of life, infants experience an increase in total sleep cycle length (Ficca, Fagioli et al. 2000). Data from a 2015 systematic review (Dixley 2015) suggest that swaddling accelerates this process, significantly reducing an infant's number of sleep state changes.

Further, whilst healthy infants typically experience an increase in QS during their first year of life (Coons and Guilleminault 1982) (Fagioli and Salzarulo 1982) (Louis, Cannard et al. 1997) (Ficca, Fagioli et al. 2000, Mirmiran and Ariagno 2003), swaddled infants may experience an acceleration of this process too. A significant increase in QS duration is associated with the intervention (Franco, Scaillet et al. 2004, Meyer and Erler 2011). Nonetheless, this association is not consistent across literature. Of the five studies that explore the topic, a range of outcomes have been presented, detailed in the table below.

Table 2 Impact of Swaddling Upon Active and Quiet Sleep Durations

Study	Subjects	Finding	Appraisal
(Brackbill 1973)	n=16 "full-term, clinically normal infants". Median age was 29 days (range, 24-36).	Percentage of AS "increased sharply" under swaddled conditions.	Although each infant served as their own control, there was no distinction made between those naive to swaddling and those routinely swaddled.
(Gerard, Harris et al. 2002)	N= 26 "healthy infants. The mean age was 87 days, with a range of 24 to 180 days".	"The average sleep duration while swaddled was increased in AS sleep".	Although each infant served as their own control, there was no distinction made between those naive to swaddling and those routinely swaddled.
(Franco, Seret et al. 2005)	n=16 "healthy infants, with a median age of 10 weeks (range: 6–16 weeks)"	"Increase in time spent in QS" under swaddled conditions.	Although each infant served as their own control, there was no distinction made between those naive to swaddling and those routinely swaddled. Further, auditory stimuli were administered to determine the infants' arousal thresholds but only during AS sleep, which may have impacted the length of this sleep state.
(Richardson, Walker et al. 2010)	n=27 "healthy term infants", who were routinely swaddled at home (n=15) or naive' to swaddling (n=12)	"Neither group exhibited a difference in the percentages of sleep time spent in each sleep state".	The only study to distinguish between naive and routinely swaddled infants. Small sample size and infants did not serve as their own controls.
(Meyer and Erler 2011)	n=85 "healthy infants" (40 in the study group, 45 in the control group)	"Swaddling promotes QS".	Did not distinguish between naive and routinely swaddled infants, and infants did not serve as their own controls. The study used a 'swaddling sleeping bag' rather than a swaddle per se (see Figure 6).

Figure 6 Meyer and Erler (2011) swaddling sleeping bag

In sum, sleep is a dynamic process situated within a network of multiple, interrelated physiological processes. Many developmental changes occur to infant sleep during the first year of life, some of which seem impacted by swaddling. Although more empirical research is needed, evidence suggests that swaddling encourages infants to develop mature sleep patterns that are out of sequence with healthy circadian patterns. This dynamic could have implications for other biobehavioural systems, (temperature regulation, arousal, feeding, etc) creating a holistic and potentially hazardous feedback loop. Literature regarding sleep state (AS/QS) is notably inconsistent, warranting further research.

Part Two: Swaddling and Arousal

> *"It works like a drug, alcohol or poppy seeds: It switches off the baby" (Frenken 2011)(p90)*

Arousal is a complex multidimensional concept. Even the term 'arousal' is crude, given there is no precise definition available, and no exact sense of precisely what is increasing or decreasing (Demos 1982). The topic of infant arousal has been of interest to the scientific community since the 1950s and 1960s, eras characterised by a boom in so-called "pacification research" (Brackbill and Fitzgerald 1969)(p180). During this period, scholars started investigating the mechanisms supporting the relationship between swaddling as a form of "sensory input of a monotonous character" (Brackbill and Fitzgerald 1969)(p177) and arousal. They spoke of the "paradox" of quieting infants through continuous stimulation (Brackbill 1971)(p26). The soporific effects of swaddling and the seemingly dissociative state of swaddled infants even led to the hypothesis that swaddling induced a degree of 'hypnosis' (Black 1967, Hoskovec 1969).

The Movement Hypothesis

Over subsequent decades, differing epistemological theories of arousal have emerged. Some frame arousal in terms of a binary threshold or ‘gate’ (Gerard, Harris et al. 2002). This concept includes startles in the repertoire of arousal behaviours but distinguishes them from full awakenings. Adopting this view, scholars have found that when infants are swaddled, fewer of their startle responses passed through the ‘gate’ into full awakening (Brackbill and

Fitzgerald 1969, Gerard, Harris et al. 2002, Thach 2002). They posit that swaddling undermines the cortical arousal process in which homeostatic reflexes and motor movement act together. In this vein, the arousal process begins with the startle and is followed by stereotyped whole body "thrashing" movements, which help to complete the process (Thach 2002)(p37). Interestingly, Wulbrand and colleagues (Wulbrand, McNamara et al. 1998) found that degree of motor activity present in startles predicts the duration of subsequent arousal related activity in the thalamus.

The potentially important role of motor movement on the pathway to full arousal is illuminated by data linking processes used in motor activity with the same neural pathway as processes used in arousal from sleep (Sherrington 1973, Thach 2002). Not only does swaddling prevent motor activity that would ordinarily turn a startle into a full awakening (Lipton, Steinschneider et al. 1965), when swaddled infants *do* fully arouse, they return to sleep more rapidly (Gerard, Harris et al. 2002).

The Overload Hypothesis

In contrast to the movement hypothesis, other scholars have advanced the idea that the continuous stimulation of swaddling effectively 'overloads' the infant's sensory system. In doing so, it 'drowns out' competing stimuli thereby raising the sensory threshold for arousal (Brackbill 1975, Lester and Boukydis 1985, Marshall.J. 2011). The hypothesis appreciates that the infant brain is significantly less developed than the adult (Faure and Richardson 2006). It also functions in line with Polyvagal Theory, discussed below, and has been supported by data showing an increased arousal threshold in swaddled infants in response to external stimuli (Brackbill 1971, Horne 2018). Indeed, Brackbill's observation of a "paradox" of quieting infants through continuous stimulation (p26), alludes to the overload hypothesis.

The Enhancement Hypothesis

Whilst the Movement and Overload hypotheses centre on the notion that swaddling decreases arousal, one study has presented a significantly different conclusion. Franco and colleagues (Franco, Scaillet et al. 2004) suggest that swaddled infants are in fact *more* sensitive to stimuli. The authors administered a stressful auditory stimulus to swaddled infants during active sleep and found larger increases in heart rate than their unswaddled counterparts[5]. Relatedly, arousal responses may differ according to stimulus type. Franco delivered one stimulus (auditory), however a review by Richmond and colleagues (Richmond, Lipton et al. 1962) provided evidence of considerably different reactions, in the same infant, to different stimuli (e.g., auditory, tactile).

[5] It is possible that swaddling impacts the sympathetic nervous system differently during AS than during QS. In other nap studies, arousals were less frequent when infants were swaddled and in QS but increased during AS (Gerard, Harris et al. 2002). Swaddled newborn birds and mammals have demonstrated similar differentiation by sleep stage (Anderssen, Nicolaisen et al. 1993).

Architectural theories aside, there is significant evidence to suggest that interference in arousal mechanisms is an important dynamic in Sudden Infant Death Syndrome (SIDS) (Byard and Krous 2001). The syndrome is thought to result from a fault of the automatic nervous system in which structures fail to mount compensatory responses to threat, such as a drop in blood pressure or respiratory obstruction (Harper 2001, Paluszynska, Harris et al. 2004). Certainly, arousal has been labelled as "the most compelling general hypothesis" (McKenna 2004)(p506). Prior to their deaths, SIDS victims sleep for longer periods, wake less often and display marked difficulty in arousing when compared to healthy infants (Einspieler, Widder et al. 1988, Harper, Leake et al. 1988). It is therefore imperative to ascertain the modifiable factors that impact infant sleep and arousability. As SIDS is only known to occur in humans (McKenna 1986, Rognum 1995, Byard and Krous 2001, McKenna 2004), it is plausible that a man-made "mechanical aid", like swaddling, may pose such a factor (Lancy 2007)(p2). In their study of 27 breastfed infants, Richardson and colleagues (Richardson, Walker et al. 2010) noted that infants naive to swaddling "exhibited decreased spontaneous cortical arousal, similar to responses observed in future victims of sudden infant death syndrome" (p87).

In summary, by undermining arousal at a time in human development when arousal mechanisms are underdeveloped, swaddling may handicap an infant's ability to handle a regulatory crisis, such as prolonged apnoea. This risk may be particularly acute for infants who are unaccustomed to swaddling.

Part Three: Swaddling and The Nervous System

> *"All those who have been found in this situation [i.e. swaddled] had a purple face; the violently compressed chest not allowing the blood to circulate, it mounted to the head, and the patient was believed to be tranquil because he did not have the strength to cry out"* (Rousseau, 1762, as cited in Lipton, Steinschneider et al. 1965).

The "most complex and important circuit in the human body" (Goh 2017)(p58), the nervous system consists of two equally vital components: the sympathetic nervous system (SNS) and the parasympathetic nervous system (PNS). The former promotes a fight, flight or freeze response, corresponds with arousal and energy generation, and inhibits digestion. The latter promotes calming of the nerves in line with regular function and enhances digestion. Interactions between the sympathetic and parasympathetic systems can be measured by a breathing process called respiratory sinus arrhythmia. When a deep breath is taken, the SNS is activated resulting in increased heart rate. Exhaling, in turn, activates the PNS, which slows down the heart. Thus, during normal respiration the heart continually speeds up and slows down, meaning the interval between two successive heart beats is never identical (Song and Lehrer 2003) (van der Kolk 2014, Zimmerman and Thompson 2016). Measurement of this process is called Heart Rate Variability (HRV). Continuous variations in heart rate reflect the body's ability to adjust to internal and external physiological changes in order to maintain homeostasis. High HRV illustrates that both SNS and PNS are functioning in balance and is deemed a good clinical indicator of overall wellbeing (Oliveira, Martins et al. 2019).

Within this context, stress is understood as a state of threatened homeostasis between the SNS and the PNS (Chrousos and Gold 1992). The component of the PNS responsible for returning the body back to homeostasis following activation of the SNS is called the vagus nerve. The longest cranial nerve, it trails from the back of the skull through to the abdomen and branches out to the heart, lungs, ears, voicebox and other areas of the body (Berthoud and Neuhuber 2000). In studies of infant development, vagal activity is considered a correlate or predictor of normal and abnormal biobehaviours. Having an increased vagal tone means the body can relax faster after stress. The reverse is true for low vagal tone.

Polyvagal Theory: The 'Shutdown' Response

In 1994, during a study of vagal activity in infants, Porges noted that the vagus nerve consisted of two distinct circuits, each stemming from a different area of the brain stem. He termed this observation 'polyvagal theory' and traced its existence back to our reptilian ancestors (Porges 2007, Porges 2009, Porges and Furman 2011).

Polyvagal Theory draws upon the interplay between the visceral experience of one's own body and external inputs from the environment around us. It builds upon the study of what Darwin referred to as the 'pneumogastric nerve' (Darwin and Rachman 1872). In reptiles, this nerve elicits a 'freeze or play dead' behavioural response to perceived threat. In addition to this, the nervous system of mammals evolved a 'fight or flight' response in order to flee or counter potential predator attacks, and also a 'tend or befriend' response present in the urge to seek out the social group for defence (Taylor, Klein et al. 2000). Perceived level of safety is thought to determine which response is activated at a given time. In his seminal work, van der Kolk describes the human stress response process as hierarchal:

> *"Whenever we feel threatened, we instinctively turn to the first level, social engagement. We call out for help, support, and comfort from the people around us. But if no one comes to our aid, or we're in immediate danger, the organism reverts to a more primitive way to survive: fight or flight… However, if this fails - we can't get away, we're held down or trapped - the organism tries to preserve itself by shutting down and expending as little energy as possible. We are then in a state of freeze or collapse" (van der Kolk 2014)(p83).*

A shutdown or 'shut-off' response has been observed in stressed infants exposed to novel stimuli (Fraiberg 1982, Sadeh 1996). Indeed, in both the medical and psychological literature, the terms 'stress' and 'trauma' are used to refer to "unusual events" or "significant change" (Sadeh 1996)(p686). Further studies by Porges and colleagues (Feldman 2012, Atzil and Gendron 2017) revealed a possible mechanism for a freeze response to stress. They discovered that infants < 6 months old have an immature vagal tone. This condition has a profound effect on how their nervous system responds to stimuli. When vagal tone is underdeveloped, the ability of the system to return to homeostasis after a challenge is weaker (Goh 2017). One issue to consider is whether the intense whole-body stimulation of swaddling may activate a similar freeze or shut down response by flooding the nervous system with sensory input. Faure and Richardson describe the infant's reaction to proprioceptive-tactile overstimulation as "much like a computer that freezes when it receives too many commands

- he falls asleep" (Faure and Richardson 2006)(p17). They maintain that falling asleep serves the function of resetting the sensory system. Infants in noisy, brightly lit neonatal nurseries have also been known to adopt this 'defensive', dissociative state (Tronick, Als et al. 1979).

A response to stress?

To date, swaddle studies have failed to produce consistent findings, with reports of increased, decreased, and unchanged HRV (Lipton, Steinschneider et al. 1960, Lipton, Steinschneider et al. 1965, Labbok 2001, Richardson, Walker et al. 2010, Kommers , Carola et al. 2019, Moller, de Vente et al. 2019). Crucially, most have failed to differentiate between infants routinely swaddled and those naïve to the intervention. The tightness of the swaddle is another neglected variable.

Although the polyvagal 'freeze/collapse' response remains theoretical, the atypical sleep length observed in swaddling studies provides support for the theory. "Are swaddled babies really happier, or does swaddling cause newborns to shut down?" questioned one clinician (Mohrbacher 2010)(p3). Another, after observing swaddled infants on a Russian postnatal ward, proposed that restriction of movement intensifies activation of infants' sympathetic nervous systems. Bystrovia found that once infants were taken from their mothers to the neonatal nursery, their foot temperature decreased significantly, and this effect was even more pronounced in those that were swaddled (Bystrova, Widstrom et al. 2003). This finding is germane given that temperature serves as a very sensitive index of cortisol levels. In adults, psychological stress exposure has shown to result in changes in skin temperature that follow a gradient-like pattern, specifically with decreases at distal skin locations such as the foot and unchanged skin temperature at proximal regions such as the neck (Vinkers, Penning et al. 2013).

More recently, the Irish Neonatal Health Alliance maintained in their guidance for neonatal units, "Some babies find being contained to be a stressful experience" (Heffernan 2019)(p10). Certainly, the observation of other physiological parameters strengthen the presumption of stress in swaddled infants. Several studies have shown swaddling to produce a significant increase in heart rate (HR) (Brackbill 1971, Gerard, Harris et al. 2002, Richardson, Walker et al. 2010) leading one researcher to posit that "the nervous innervation resulting from continuous stimulation modifies adrenergic functioning" (Brackbill 1975)(p46). Indeed, increase in heart rate closely parallels the physiological consequences of stress (Tronick, Als et al. 1979). It is the antithesis of Heart Rate Variability (HRV).

In an early case-control study, Lipton recorded reduced HRV in swaddled infants compared with non-swaddled infants, another classic marker for stress (Lipton, Steinschneider et al. 1965). A further study documented higher respiratory rates in swaddled infants, suggestive of reduced HRV (Song and Lehrer 2003). In this vein, Bystrova and colleagues (Bystrova, 2007, Bystrova, Widström et al. 2007; Bystrova, 2003, Bystrova, Widström et al. 2007) and Mohrbacher (Mohrbacher 2010) found greater weight loss in swaddled infants relative to un-swaddled infants and framed this as a result of the stress induced by physical restraint. Later, Bergman cited the work of neurophysiology (Misslin 2003), outlining a possible infant freeze response similar to polyvagal theory:

"When the perceived threat is closer than the mother, or if the mother is not responding, a cry response would increase danger, thus a state of freeze follows... Such babies lie absolutely still, absolutely quiet, with eyes firmly closed. This is believed to be sleep! It is however a state of high arousal, also called 'fear-terror'" (Bergman 2014)(p2).

Given the evolutionary roots of our response to stress, could bioanthropology shed further light on the phenomenon? In the 1990s bioanthropologists discovered that during close proximity and sleep contact, mothers and infants engage in mutual physiological regulation of their sleep and arousal architecture (Mosko, 1997, Mosko, Richard et al. 1997;Mosko, 1996, Mosko, Richard et al. 1997). This finding was later supported by the work of developmental social neuroscientists who revealed that an infant's vagal tone is interrelated with their mother's and indeed co-regulated by it (Stone 1971) Feldman, Gordon et al. 2010, Feldman, Magori-Cohen et al. 2011, Feldman 2012) (Yoon, Choi et al. 2019). Considering the bidirectional nature of the mother-infant relationship, swaddling, as a physical and visual barrier, could be considered to initiate stress via maternal-deprivation. This makes intuitive sense as attachment is crucial for survival in both humans and animals (Bowlby 1969). Any disruption of the attachment relationship can be experienced as a serious threat and "cause significant distress" (Sadeh 1996)(p688). Swaddling undermines the maternal regulatory role, preventing mothers from delivering appropriate responses. It interferes with biological processes, such as the exchange of oxytocin, central to attachment and stress management (Meaney 2010, Feldman 2012) . These systems rely on tactile contact (Calkins and Hill 2007, Feldman, Singer et al. 2010). Touch stimulates the vagal nerve, increasing parasympathetic activity (McKenna 2016).
It is therefore conceivable that the effects of swaddling would mirror those of other infants separated from the tactile regulation of their mothers. Morgan (Morgan, Horn et al. 2011) found that separated infants experience patterns of nervous system activity that mirror those previously described as 'threat responses' (Perry, Pollard et al. 1995). In a study of extinction sleep training (letting infants 'cry it out' alone), Middlemiss and colleagues examined the psychological response to separation and found that infant cortisol levels remained elevated long after the infant had stopped crying (Middlemiss, Granger et al. 2012). Interestingly, scholars have observed a similar response in swaddled infants. Fauntleroy postulated: "The baby is staying quiet but is not relaxed or happy; That led me to conclude the baby is shutting down" (Fauntleroy 2012)(p1).

Exposure to stress (whether acute or chronic) can have pronounced effects on the sleep architecture of both animals and humans (Van Reeth, Weibel et al. 2000). Stressful events trigger the hypothalamic–pituitary–adrenal axis (HPA axis) - a complex set of feedback interactions between the hypothalamus, the pituitary gland and the adrenal glands. The HPA axis plays an important role in sleep–wake regulation and in alterations of the sleep–wake cycle (Van Reeth, Weibel et al. 2000). Adjustments in sleep pattern seen after stress engage restorative process that compensate for stress overshoot (Descamps and Cespuglio 2010). The reaction of reduced arousal and prolonged sleep seen in swaddled infants could therefore be a result of activation of the HPA axis or what van der Kolk calls the 'ultimate emergency system':

"This system is most likely to engage when we are physically immobilized, as when we are pinned down...It induces shallow breathing. Once this system takes over, other people, and we ourselves, cease to matter. Awareness is shut down, and we may no longer even register physical pain" (van der Kolk 2014)(p83).

As detailed in the clinical literature review, infants demonstrate significantly reduced behavioural and physiological reactions to pain while swaddled. In fact, a review of systematic reviews on pain interventions in hospitalized infants identified swaddling as one of the most impactful non-pharmacological practices for procedural pain (Yamada, Stinson et al. 2008). The exact pain-relieving mechanism of swaddling is unclear, however scholars (Efe, Dikmen et al. 2013, Villacres and Chumpitazi 2018) have hypothesised it to be rooted in the act of sensory stimulation or in 'sensory distraction'. This notion aligns with the argument, noted above, that swaddling equates to sensory overstimulation.

Animal 'Swaddle' Studies

Biobehavoural researchers suggest animal models offer the best approximation to an understanding of stress mechanisms in humans (Buynitsky and Mostofsky 2009). Drawing parallels with the swaddling of human infants (Toth, Aleman et al. 2012), scientific and clinical researchers have manipulated animals' environments with the aim of triggering and examining the stress response. Due to its effectiveness at eliciting both physiological and psychological stress, most experiments have relied upon the use of immobilization or restraint (Buynitsky and Mostofsky 2009). Methodology varies from a single session of 5 min motor restraint (Jackson and Moghaddam 2006, Kang, Cirrito et al. 2007), to sessions lasting up to three weeks (Davydov and Shvets 2003, McLaughlin, Gomez et al. 2007). Techniques include swaddling the animal in a hammock or placing them into a tight-fitting sleeve (McCarley and Hobson 1971, Finch, Feld et al. 1978, Kiiatkin and Zhukov 1986, Al'bertin and Golovacheva 2002). Data from this field highlight the impact of motor restraint on the 'fight or flight' response, the freeze response, the immune system, food intake, and energy and mineral metabolism.

Substantial evidence in this field has demonstrated that motor restraint is one of the most stressful events for laboratory animals, as shown on a rating scale of invasiveness (Shapiro and Field 1987). Consequently, the term 'Immobilization stress' was coined to describe the resultant cluster of neurotic disorders, characterised by visceral and somatic disturbances (Shapiro and Field 1987). Animals subject to immobilization have also shown disruption in endocrine and gastrointestinal functioning and a reduction in the normal functioning of nerve cells and neuromediators (Tache, Du Ruisseau et al. 1976, Tache, Ducharme et al. 1980, Charpenet, Tache et al. 1981, Roske, Rathsack et al. 1983, Hauger, Lorang et al. 1990, Almeida, Anselmo-Franci et al. 1998, Roske, Hughes et al. 2002). One common consequence of immobilization, and pertinent to the purposes of this review, is the falling of the animal into a drowsy state. When this occurs, the researcher is required to use psychostimulant drugs in order to keep the animal awake for study (Noda, Freeman et al. 1971).

In the field of biosensory engineering, research of both animals and humans has revealed that applying clothing pressure to the body impacts nervous system functioning, reducing metabolic rate, pulse rate, muscle tone, and oxygen consumption, a mechanism initially termed 'the skin-pressure reflex' (Kumazawa 1963, Kosaka, Takagi et al. 1967, Takagi and Kobagasi 1980) and labelled by later scholars as 'the skin pressure vegetative reflex' (Backon and Kullok 1990, Backon 1991, Backon and Hoffman 1991, Backon 1992). Contemporary veterinarians refer to this phenomenon as "squeeze-induced somnolence" and hypothesise that restraint "may resemble the effects of compression of the fetus in the birth canal and lead to inhibition of voluntary activity" (Pickles 2014)(p4).

Whilst the topic of 'restraint stress' continues to dominate stress-induced methodology in animal studies, the approach has not extended to human participants in the form of swaddling. This is surprising given that a child's early exposures to stress shape the functioning of their stress-response systems (Morgan, Horn et al. 2011, Miller and Commons 2014). There are no known studies of swaddled infants examining the stress response, for instance involving cortisol data, or investigating whether other neurophysiological parameters are normal or altered. The very nature of swaddling as a widespread practice and popular neonatal intervention underpins the need for interrogation of the stress response in this field. Further research should explore the cortisol levels of swaddled infants. As cortisol levels typically do not rise during sleep (Horne 2000), a finding of elevated cortisol may confirm consciousness in infants who otherwise appear to be sleeping. Alternatively, elevated cortisol of swaddled infants may indicate pathology of sleep architecture. Enquiry should include longitudinal data to determine developmental effects. This is crucially important for vulnerable infants, such as those born prematurely or regularly undergoing medical procedures who, despite having already-compromised nervous systems, routinely spend most of their early life under various forms of motor restraint (Zarem, Crapnell et al. 2013, Penn Medicine 2019).

Part Four: Swaddling and The Respiratory System

The primary muscle used in respiration is the diaphragm. Anatomically, the diaphragm is a thin dome-shaped sheet dividing the upper thoracic cavity and a lower abdominal cavity. Functionally, this muscle is thought an important source of information relating to the entire body (Kocjan, Adamek et al. 2017). It is important for postural control and plays a vital role in the vascular, lymphatic and gastroesophageal systems. Regarding the latter, the diaphragm regulates functions such as swallowing and vomiting, and contributes to the gastroesophageal reflux barrier (Kocjan, Adamek et al. 2017). Dysfunction of the diaphragm can cause poor swallowing or sleep apnoea (Kocjan, Adamek et al. 2017).

Until around three months of age, ventilation is maintained by increasing respiratory rate rather than volume (Givan 2003). As the chest muscles are not fully developed at the time of birth, infants use their abdominal muscles much more than adults to pull the diaphragm down for breathing. The combination of underdevelopment of breathing muscles and the immaturity of the respiratory system mean that infants operate at a 'mechanical disadvantage' (Givan 2003). Infants are especially susceptible to a variety of breathing difficulties and this is worsened by the fact that much of their time is spent horizontally (Givan 2003).

"Swaddling should be snug around the chest" recommends the American Academy of Pediatrics (Moon and Task Force On Sudden Infant Death 2016)(p7), but this restriction may reduce the ability of the diaphragm to draw air into the thoracic cavity. When this occurs, a compensatory increase of abdominal expansion is observed (Kocjan, Adamek et al. 2017).

Continued restriction of the diaphragm leads to shallow breathing and an increase in respiratory activity (Kahn, Groswasser et al. 1992). This may lead to impairment of gas exchange, and result in hypoxia or hypercarbia, which are risk factors for apnea in young infants (Li, He et al. 1986). Indeed, several swaddling studies have shown increase respiratory frequency linear with the tightness of the swaddle (Gerard, Harris et al. 2002, Richardson, Walker et al. 2009, Richardson, Walker et al. 2010, Meyer and Erler 2011, Nelson 2017). The inability of swaddled infants to perform postural alterations may undermine their regulatory response to this scenario. Periodic changes in body position as a result of unswaddled infant startles or 'thrashing' are thought important for airway protection (Thach 2002).

Despite a body of literature associating swaddling with changes in respiratory rate, there is currently no definitive evidence suggesting a direct link between the intervention and respiratory infection (Nelson 2017). One large descriptive study of infants swaddled in layers of cloth "pulled tightly" found those swaddled for a minimum of 3 months were four times more likely to develop pneumonia and acute respiratory infection than never swaddled infants (Yurdakok, Yavuz et al. 1990) (p873). Yet a later study reported no swaddle-related increase in pneumonia (Manaseki-Holland, Spier et al. 2010).

In sum, the literature is clear that swaddling impacts respiratory rate, with tightness serving as a key variable. Under conditions of stress such as respiratory infection, the inability of the infant's swaddled diaphragm to compensate for increased respiratory load could theoretically worsen illness or prognosis (Narangerel, Pollock et al. 2007).

Part Five: Swaddling and The Thermoregulatory System

Infant thermoregulatory outcomes are largely dependent upon their caregiver's interpretation of their thermal needs (World Health Organization 1997) and caregiver beliefs regarding appropriate ways to address those needs (Winch, Ashraful et al. 2005). The topic of infant temperature regulation showcases how cultural variance intercept with biological concerns. For instance, White British mothers are shown to worry about overheating causing Sudden Infant Death Syndrome (SIDS), whereas South Asian mothers demonstrate more concern about cold causing respiratory infections (Cronin-de-Chavez, Ball et al. 2016). This diversity is interlaced by socioeconomic influences, with poorer Western mothers demonstrating greater concern about cold than their wealthier counterparts (Cronin-de-Chavez, Ball et al. 2016). The focus of parental concern influences caregiving behaviour and in turn, the infant's biobehavioural response.

Responses to cold and heat are particularly germane during the first three months of life - the most common swaddling window and a peak age risk for SIDS – when an infant's immature thermoregulatory system undergoes complex developmental changes (Fleming, Azaz et al. 1992). A change in environmental temperature can cause unpredictable changes in respiration due to potential changes in metabolism (Givan 2003). Indeed, SIDS risk has known to increase with both hyperthermia (American Academy of Pediatrics 2000) and hypothermia (Williams, Taylor et al. 1996). Colder nighttime ecologies leave infants more prone to infections that increase SIDS-risk (Molony, Blackwell et al. 1999, Fleming and Young 2006), and in this vein, swaddling may serve a protective function. Wrapping techniques that maintain flexion of the limbs serve to decrease body surface area, and in turn minimise heat loss (Wheldon 1982, Ellis, Manandhar et al. 2006). The warmth provided by bundling may be a factor driving the increase in sleep duration commonly seen in swaddled infants, as discussed below (Manaseki-Holland 2010). Both infants and adults experience increased wakefulness (Fleming, Azaz et al. 1992) and reduced continuity of sleep (Telliez, Bach et al. 1998) (Bach, Telliez et al. 2000) in cold environments.

Within this context, some argue that swaddling may have value in postnatal settings. At birth, healthy newborns experience "large, evaporative, convective, and radiant heat loss" (Abbot and Watkinson 2008)(p387). To minimize this, many clinical settings routinely dry, swaddle or place neonates under an overhead heat source (Abbot and Watkinson 2008). For very low birth weight (VLBW) infants in an incubator, swaddling has shown to increase abdominal temperature by 0.2°C (Short 1998). Maintaining body temperature within optimal thermal range is central to the survival of such infants. A swaddle blanket provides insulation, reducing the emissivity of the skin and changing air velocity and airflow patterns around the infant (Thomas 1994, Silva, Laszczyk et al. 2016). However, layering and tog value are important considerations. Swaddling healthy infants with thermal value of greater than 10 togs is independently associated with an increased risk of hyperthermia, particularly in infants older than 70 days (Fleming, Gilbert et al. 1990) (Gilbert, Rudd et al. 1992). Unsurprisingly infants swaddled in five blankets and a hat show a rise in body temperature into the febrile range (Cheng and Partridge 1993).

Interestingly, a randomised controlled trial comparing the effects of swaddling with use of an infant sleeping bag of equal thermal tog found no differences in infant core, peripheral, or microenvironmental (inside bedding but outside clothing) temperature between the two conditions (Tsogt, Maniseki-Holland et al. 2006). Similarly, a study of routinely swaddled infants found no difference in abdominal skin temperatures between those sleeping swaddled and those sleeping with a blanket placed over their body (Richardson, Walker et al. 2009), and one Russian hospital-based study observed that tightly swaddled newborns showed a *delay* in temperature elevation compared to unswaddled infants (Bystrova, Widstrom et al. 2003).

It is thus possible that motor restraint poses a biobehavioural hurdle to effective temperature regulation. Unlike adults, infants do not regulate their body temperature by sweating or shivering. The maternal body helps the infant to thermoregulate, enabling them to maintain a higher temperature more efficiently, thus conserving energy (McKenna 2016). When not with their mother, they have been observed to adopt postures to cool down or warm up (Faure and Richardson 2006). Cold infants tend to be more wakeful and active, moving their limbs, whereas hot infants have been observed to adopt a 'starfish' position by extending the arms and legs (Faure and Richardson 2006). Swaddling prevents both maternal skin-to-skin contact and infant postural adaption.

In addition to behavioural considerations, thermoregulatory responses are also influenced by sleep state. Warm sleep ecologies induce more frequent and longer apneas (Bader, Tirosh et al. 1998) and increase rates of periodic respiration, especially during active sleep (Berterottiere, D'Allest et al. 1990). In contrast to adults who experience impairment of thermoregulation during REM sleep (Parmeggiani and Rabini 1970), infants experience maintained or even enhanced thermoregulation during active sleep, their version of REM

(Darnall and Ariagno 1982, Stothers and Warner 1984, Fleming, Levine et al. 1988, Bach, Telliez et al. 1996, Bach, Telliez et al. 2002). Despite greater heat production during active sleep (AS), internal temperature recordings do not differ from those recorded during quiet sleep (QS) (Stothers and Warner 1984, Fleming, Azaz et al. 1992, Bach, Bouferrache et al. 1994), suggesting a reduction in infant body insulation during AS (Bach, Telliez et al. 2002).

As a result of most studies adopting a reductive awake/asleep coding framework, little is known about thermoregulatory responses to swaddling in relation to AS and QS. In non-swaddled infants, frequency of body movements markedly differ during AS compared to QS (Bach, Bouferrache et al. 1994, Bach, Telliez et al. 2002). The motor restraint of swaddling may theoretically impede aspects of thermogenesis that would otherwise be accomplished through muscular activity.

Overall, temperature regulation is understood in the swaddle literature as resulting from a dynamic interaction of factors; this includes infant health and size, layering of wrappings/covers, tog value and a possible discord between motor restraint and adaptive responses to temperature disequilibrium.

Part Six: Swaddling and Feeding

Infant feeding is a simultaneously biological and cultural phenomenon. Despite being a natural and necessary act, infant feeding, and breastfeeding in particular, is a controversial topic in WEIRD settings (Western, Educated, Industrialized, Rich and Democratic) (Henrich, Heine et al. 2010). This irony is strengthened by the fact that most research on the topic is conducted in those settings (Henrich, Heine et al. 2010, Nielsen, Haun et al. 2017). The influence of swaddling on this topic is unclear. A 2007 systematic review found no correlation between swaddling and infant breastfeeding behaviour. However, every randomized control trial featured in the review compared swaddling that took place in the context of other WEIRD practices involving separation of infants from their mothers, for instance, the use of incubators or pacifiers (van Sleuwen and L'Hoir 2007). Other scholars have drawn parallels between cultures in which infant sleep interventions are popular and poor rates of sustained breastfeeding (Ball, Taylor et al. 2020).

The Immediate Postnatal Period

One randomised control trial eloquently demonstrated the problematic role of feeding research conducted in WEIRD settings. Moore and Anderson (Moore and Anderson 2007) found infants who suckled competently during their first 2 hours of life did so regardless of whether they experienced skin-to-skin contact with their mother or were swaddled. This appears to suggest that swaddling has little, if any, impact on breastfeeding establishment. Arguably these findings must be absorbed with caution however, given the small sample size (n=20), the status of the mothers as primiparas, their robust motivation to breastfeed (unusual in WEIRD settings) and a source of the research funding originating from an infant bottle manufacturer.

Research conducted in more diverse postnatal settings illuminate a contrasting dynamic. In their 2007 study of Russian maternity home routines, Bystrova and colleagues (Bystrova, Widstrom et al. 2007) observed that infants swaddled in the first few days after birth experienced a delay in initial breastfeeding, less successful suckling at the breast, reduced intake of breastmilk and more weight loss. In Thailand, 'moderately snug' swaddling is widely practiced and supported alongside breastfeeding and rooming-in (White, Carrara et al. 2012). Surprisingly, this culture has a full-term breastfeeding initiation rate of 91.2% within 1 hour of delivery, and an average breastfeeding duration of 19 months (White, Carrara et al. 2012). In this vein, it is plausible that a supportive environment is a more dominant predictor of breastfeeding performance than swaddling.

Separation and Biobehavioural Consequence

An emerging hypothesis in the field of infant nutrition asks whether parenting style influences responsiveness to hunger cues or whether responsiveness is simply part of distinct parenting beliefs or 'parental ethnotheories' (Harkness and Super 2006, Little, Legare et al. 2018). In exploring this hypothesis, Little and colleagues (Little, Legare et al. 2018) found that mother–infant physical contact, reflected in parenting practices such as bedsharing or sling-use, increased maternal responsiveness to infant hunger cues in comparison with visual cues (without physical contact). This finding remained even after parental beliefs about responsiveness were controlled for. The authors concluded that there is "something special about direct physical contact that facilitates infant-led motivations for feeding above and beyond just having the infant in proximity". Certainly, physical separation is associated with decreased breastfeeding (McKenna, Mosko et al. 1997, Hauck and Kemp 1998, Ball, Ward-Platt et al. 2006, McKenna, Ball et al. 2007). Even separation via the wall of a hospital bassinette placed next to the maternal bed has been shown to exert physiological and psychological influences on the behavioural and biological relationship between infant and mother (Ball and Klingaman 2008).

It is then perhaps ironic that the biomedical model recommends a responsive approach as the optimal feeding strategy (Woolridge 1995, Harvey and Haldeman 2006, Brown and Arnott 2014, Murkoff and Mazel 2014, Shloim, Vereijken et al. 2017). Responsive feeding involves the caregiver initiating feeding upon noticing the infant's display of early hunger cues and then terminating feeding when the infant shows signs of satiety (American Academy of Pediatrics 2017). Early hunger cues may include mouthing hands or objects, making sucking noises or motions, clenching fingers or fists over the torso, flexing arms and legs, or engaging the rooting reflex. Crying, on the other hand, is considered a “late” hunger cue (Harvey and Haldeman 2006, Hodges, Hughes et al. 2008, American Academy of Pediatrics 2017). Like the walls of a hospital bassinette, swaddling may obscure feeding cues and provide a proximal barrier to mother-infant interaction.

Responsive feeding is related to another aim, the concept of 'shared feeding responsibility', recently promoted to prevent obesity from as early as infancy. The concept positions parents in the role of provider of healthy food whilst the child's role is to decide how much to eat based on their hunger and satiety cues (Paul, Savage et al. 2018). Swaddling arguably undermines both the mother’s and the infant’s role in the shared feeding exchange. ‘Celebrity paediatricians’ such as Karp, advocate swaddling prior to feeding (Karp 2018). Following this advice, the barrier of swaddling prohibits skin-to-skin contact, thus undermining mothers' regulatory abilities. For breastfeeding mothers, swaddling negatively interferes with the ability to adopt optimum positioning (Charlmers 2005). One lactation specialist observed that swaddling encourages a mother to "cradle her cueless, clueless baby supine in her arms, being sure to support the head, while trying to point a nipple into his mouth" (Genna 2017)(p127). This positioning, she highlights, is not conducive to successful breastfeeding.

For infants, tight swaddling may impede the coordination of swallowing and respiration required to feed. It delimits their capacity to mould their body to their mother's, to nestle, and to actively move in order to participate. The continuous sensory load of swaddling may be particularly problematic for infants described as highly sensitive to touch; the gag reflex of such infants can be triggered by pressure applied to non-oral body parts, such as the arm or shoulder (Scarborough, Boyce et al. 2006), locations typically stimulated via swaddling.

Swaddling and Feed Frequency: Detriment or Remedy?

Thanks to critical bioanthropological research, in addition to feed style there is a growing appreciation in the of the fundamental role of feed frequency in modulating human milk supply (Ball, Ward-Platt et al. 2006, Ball and Klingaman 2008). The process of lactation involves two maternal hormones. Prolactin acts on the milk-making tissues and oxytocin causes the breast to push out or 'let down' the milk. A variety of stimuli can trigger the release of these hormones, including the sight, smell, sound and feel of an infant. A hormonal surge is experienced with every feed or attempted feed. Around forty-five minutes after feeding, the surge declines. Repeated feeding maintains circulating blood hormone levels and protects a robust milk supply (Tennekoon, Arulambalam et al. 1994, Woolridge 1995, Neville 2001). In this vein, the American Academy of Pediatrics suggest that breastfed newborns should feed eight to twelve times every 24 hours. Swaddled infants, however, have been shown to feed no more than six or seven times in a 24-hour period (Franco, Seret et al. 2005).

One potential reason for this discrepancy is that swaddling undermines or mediates the biobehavioural processes associated with hunger. Firstly, the increased cortisol production associated with separated infants reduces infant appetite (McKenna 2016). Swaddling is technically a form of physical separation, given that at the very least, it prohibits skin-to-skin contact. Scholars have noticed that weight gain correlates positively with the amount of daily touch infants receive, leading some to hypothesise that touch may make the absorption of calories more efficient by speeding up digestion (Field 1996, 1998, as cited in McKenna 2016). This could suggest that swaddling reduces metabolic efficiency.

As well as potentially suppressing behavioural systems associated with hunger, swaddling is well established to lower arousals that are accompanied with infant signalling. In a prototypically WEIRD study, Van Sleuwen and L'Hoir (van Sleuwen and L'Hoir 2007) linked swaddling with a reduction in 'excessive crying' and concluded that the intervention may be useful in the prevention of overweight and obesity, "as parents of excessively crying infants have the tendency to offer extra feeds" (van Sleuwen and L'Hoir 2007)(p3). In this sense, Van Sleuwen and L'Hoir cite lengthened sleep as another virtue of swaddling in the 'war against obesity', given the possible link between short sleep duration and the disease (Taheri 2006).

The intriguing prospect that infant sleep duration may be a modifiable risk factor for obesity has inspired several American clinical trials (Gillman, Rifas-Shiman et al. 2008, Redsell, Atkinson et al. 2011, Anzman-Frasca, Liu et al. 2013, Gross, Mendelsohn et al. 2016, Savage, Birch et al. 2016, Paul, Savage et al. 2018, Lavner, Stansfield et al. 2019, Harris, Anzman-Frasca et al. 2020). Among them were the Healthy Beginnings Trial (Wen, Baur et al. 2012), the Intervention Nurses Start Infants Growing on Healthy Trajectories (INSIGHT) (Paul, Williams et al. 2014) and NOURISH-RCT (Daniels, Mallan et al. 2012). A common feature of each trial was the introduction of swaddling. Grounded in developmental theory on parenting sensitivities, the trials' conceptual framework maintained that by promoting infant sleeping and food-free soothing, swaddling may slow weight gain. In highlighting what bioanthropologists have known for years, one trial explained:

> *"Because infant sleep bouts are interrupted by waking to be fed, the routines parents establish around sleep can also affect feeding frequency and energy intake, with important consequences for infant weight gain" (Lavner, Stansfield et al. 2019)(p2).*

The framework echoes sentiments of the 'shared feeding responsibility' paradigm discussed above in which both parents and infants play an equally important role. Discouraging the use of feeding as the first parental response to infant distress, swaddling was promoted as one of a handful of alternative soothing strategies alongside side-stomach position, shushing, swinging, and suckling (Karp 2002). Previous randomized controlled trials of this program have demonstrated fewer nocturnal and daily feeds from age 3 to 16 weeks compared to control group infants and slower weight gain over the first year of life, particularly in breastfed infants (Anzman-Frasca, Liu et al. 2013, Paul, Williams et al. 2014, Paul, Savage et al. 2016, Savage, Birch et al. 2016).

The sum of these findings position swaddling as a novel weight regulation tool. Could swaddling be the 'drug' that combats the obesity epidemic, akin to metabolism regulating pills? Is this drug 'dose-specific'? Or could swaddling exclusively breastfed infants risk a diagnosis of failure to thrive? Despite its success at reducing feed frequency in breastfed infants, arguably swaddling could *promote* obesity in bottlefed infants. Here, intake is governed by milk flow; During feeds, infants use instinctive body language to indicate when they have reached satiation. Arching of the back, pushing away, open arms at side of body, and open or relaxed fingers, are all cues that the infant is ready to stop feeding (White and Bryan 2002). If infants are swaddled during feeds, these behaviours are masked and even disabled, providing a prime scenario for overfeeding. This risk is of particular concern within Western settings, where obesity is most prominent and where obesogenic practices such as infant feeding with artificial breast milk substitutes, are the norm (Tomori, Palmquist et al. 2017).

Part Seven: Swaddling and Cognitive Development

> *"Over the past 20 years it has become clear that even fairly innocuous-looking experiences can profoundly affect brain development and that the range of experiences*

> *that can alter brain development is much larger than had been once believed" (Kolb and Gibb 2011)(p271).*

Scholars are certain that early tactile experiences have a powerful effect on brain organization both during development and in adulthood (Kolb and Gibb 2011). Yet despite the rapid brain growth typical of infancy, examination of the cognitive development of swaddled infants has never been a popular topic of inquiry. This could be linked to the difficulty in conceptualizing infant agency and rationality that has been present in research for many years, and within anthropology particularly (Gottlieb, 2000, as cited in Ball, Tomori et al. 2019). Consequently, the potential cognitive impact of swaddling can only be speculative and largely hypothesised from what is known about the general cognitive development of un-swaddled infants.

A lack of swaddle research in this field has not however prevented some scholars issuing grand claims of the intervention. The authors of one clinical swaddle trial maintained, "Parenting interventions that increase child self-regulation may also positively affect the development of empathy, cognitive and social competence, ability to delay gratification, compliance, and academic achievement" (Savage, Birch et al. 2016)(p747). Such lofty proclamations were not echoed in the only longitudinal study to investigate this topic. In 2010 a randomized controlled trial examined the cognitive psychology of 11- to 17-month-old infants and failed to find significant difference in development between infants swaddled for 7 months and those who had not been swaddled (Manaseki-Holland 2010).

A Barrier to Exploration, or an Aid?

> *"It is the awareness that from the own bodily actions can originate systematic perceptual consequences that are controllable and explorable" (Rochat and Striano 2000)(p518-519).*

Infants are born with intersubjective mental capacities. Empirical data show the ability of newborns to distinguish self-produced perceptual events (Rochat and Hespos 1997). When they move their limbs, an infant learns to situate and differentiate themself as a unique entity in the environment (Butterworth and Hopkins 1988, Rochat, Blass et al. 1988, Morgan and Rochat 1997, Rochat 1998). Touch, for instance, is the most developed of the senses at birth. The infant mouth and fingers are particularly 'wired' for information collection (Marshall 2011). By 3 months of age, infants have developed an intermodal body-map or schema of their own body as dynamic and organized (Morgan and Rochat 1997, Rochat 1998). Around that time, healthy infants acquire enough depth perception to deliberately reach for and grab objects (Nugent 2011). Immobilization through swaddling prohibits such exploration.

Moreover, when one considers the effects of immobilization in diminishing nervous system responses, another curious paradox emerges. A small pool of evidence suggests that restricted limb movement may enhance the intake of new information. Based on findings from earlier swaddling studies (Gardner and Turkewitz 1982), Demos (Demos 2009) hypothesized that arousal and attention work interdependently as a homeostatic system. In this system, internal and external factors specify the amount of attention an infant can direct to external stimuli. This theory conflicts to a certain degree with the overload hypothesis discussed above. It maintains that by supressing movement, swaddling prevents much periodic proprioceptive stimulation of the brain, thus freeing up attentative resources. The phenomena was observed by Franco and colleagues (Franco, Scaillet et al. 2004) and taken to suggest that swaddled infants are in fact *more* sensitive to stimuli: The Enhancement Hypothesis.

A handful of other studies have illustrated this possibility. Lejeune et al sought to investigate the influence of swaddling on the visual investigative abilities of forty preterm infants (between 28 and 35 weeks' postconceptional age (Lejeune, 2021 #1781). They found that infants with greater previous swaddling experience during the week preceding the experiment spent more time and more trials looking at novel objects (prism and cylinder). In a similar study (Gardner, Karmel et al. 1992), newborns were exposed to light panels illuminated at various frequencies. Whilst swaddled, the infants showed a preference towards more stimulation (faster frequencies) than when they were unswaddled. The theory posited, that arousal and attention are interdependent processes that can be manipulated by swaddling, was also supported by Lester and colleagues (Lester, Boukydis et al. 1996). In their study, 22 premature infants and 22 full-term infants were observed in an 'active awake' state (alert, not crying) whilst swaddled. The same infants were then observed in an active awake state but unswaddled. To measure the ability of the infants to engage in 'sustained attention', the researchers encouraged their young subjects to track a red ball moved within sight. Whilst swaddled, both infant groups spent more time demonstrating sustained attention. This finding led the authors to conclude that "attention can compete with somatic demands" and therefore swaddling "helps" an infant to scan the environment (Lester, Boukydis et al. 1996)(p777).

Another potential mechanism involved in the link between swaddling and cognitive performance is the tactile nature of the swaddling experience. (Schanberg and Field, 1987 as cited in Kolb and Gibb 2011) and (Kolb and Gibb 2011) found that regular tactile stimulation, even artificial stimuli using man-made objects, lead to improved cognitive performance in rats. In their studies, infant rats were given tactile stimulation with a small brush for 15 minutes three times per day for 10–15 days beginning at birth. When the infants were studied in adulthood, they showed enhanced spatial learning.

In sum, cognitive phenomena result from a complex interaction of brain and bodily systems. The interrelationship between self-awareness and proprioception enable exploration, a fundamental driver of cognitive development. Swaddling creates discord between the infant's goal-directed cognitions, which it ironically seems to enhance, and the infant's capacity to act upon them.

Part Eight: Swaddling and Social Development

> *"A child lying stiff in swaddling clothes was unable to wave its hands and feet in the air, incapable of reaching out to grasp some dangled object, forbidden by its bonds to respond to maternal playfulness" (Shorter 1975)(p7).*

Infants are born with an innate motivation to engage in relationships (Trevarthen 2001). They are inherently proximity-seeking, repeatedly and actively pursuing attachment (Bowlby 1969, Tow and Vallone 2009). Newborns are shown to move in precise and sustained synchrony with the articulated structure of adult speech (Condon and Sander 1974, Trevarthen, Delafield-Butt et al. 2010). During interactions with their mothers, infants' hands are used gesturally and are linked rhythmically to vocalizations (Brazelton 1973, Brazelton 1973). They do this 'publicly', for other persons, 'provoking' their response (Darwin 1872, Darwin and Rachman 1872, Darwin 1877, Darwin 1887/1958), behaviour termed "intersubjective motor control" (Trevarthen 2011)(p121). Mothers interpret and decode their infant's capacities and needs through their motor cues. Many animal species communicate similarly (Sansone 2004).

How might the man-made intervention of swaddling impact upon this innate behaviour? Despite serving a relatively common presence in infancy, swaddling is largely overlooked by scholars of social development. In the 1970s, when almost 52% of parents swaddled their infants (Brackbill 1971), psychologists assured that: "Within wide limits all sorts of infant-management methods may be used without detriment to the child's emotional development, *provided the mother is in tune with the needs of the child*" (Stone 1971) [emphasis mine] (p225).

Infant posture plays a central role in eliciting regulatory input from adults. For instance, when an infant is hungry, they may suck their hands, clench their fingers or place a tight fist over their chest (NCAST 1990). When they are overstimulated, infants may place their hands to the face or clasp them together. Finger splaying or saluting, frantic disorganised movements, back and neck arching, appearing to push away, sweaty feet, and straightening of the legs can also be seen (Faure and Richardson 2006). Swaddling reduces or eliminates the scope of these micro-level warning cues, undermining this sensitive system.

Mother-infant synchrony

Not only do infant cues convey information about physical and emotional state, as mentioned above they also regulate the physical and emotional states of both transmitter and recipient (Hildebrandt and Fitzgerald 1983, Porter, Cernoch et al. 1983, Kaitz, Lapidot et al. 1992, Bornstein and Suess 2000, Hinde 2014). Drawing parallels with other mammals, Feldman (Feldman 2012) positioned infancy as a finite window of opportunity in which infant attachment-related biological systems are receptive and 'open' to behavioural influences. Synchronous interactions with attachment figures during this period may profoundly impact upon biobehavioural regulation and endure through childhood (Feldman 2012). Elements such as touch, arousal, proximity, body movement, and body position are central to developing synchrony (Feldman 2007, Barry 2020). In fact, a systematic review of mother-infant interaction associated infant "pleasurable motoric behaviour" with increased maternal attunement (Provenzi, Scotto di Minico et al. 2018)(p13). This proposal has potentially strong implications for swaddled infants, particularly in light of the recommendation of routine swaddling in preference over occasional swaddling (The Lullaby Trust 2020). The intervention visually obscures infant cues, reduces the sum of cues and reduces a mother's capacity to respond appropriately, forming an obstacle to certain infant-care acts (nappy changing, feeding positioning, skin-to-skin touch).

Indeed, several studies have shown swaddling to correlate with reduced reciprocal interactions between mother and infant (Bacon, Bell et al. 1991, Cheng and Partridge 1993, van Sleuwen, Engelberts et al. 2007). Although some degree of asynchronous behavioural mismatch is normal in all dyads (Provenzi, Scotto di Minico et al. 2018), swaddling, by design, tips the scale by undermining every dimension of mother-infant synchronicity. Swaddling reduces mutuality, delimiting the infant's contribution in terms of frequency and intensity of behaviours relative to their mother's; It delimits reciprocity, minimising the infant's reciprocal influence; It restricts matching and mirroring behaviours by prohibiting the infant from exhibiting the same postural state as their mother; For mothers, swaddling reduces attunement, undermining maternal identification of their infant's inner feelings/states; Crucially, the intervention also prevents successful reparation of dyadic mismatches - a critical process for the healthy development of infant regulation (Provenzi, Scotto di Minico et al. 2018).

From a biological view, swaddling delimits engagement of mother-infant oxytocin-dependent affiliation networks and stress management systems (Meaney 2010, Feldman 2012) given the reliance of both of these networks upon tactile contact (Feldman, Singer et al. 2010). From a behavioural perspective, swaddling cultivates a distinctive ecology that is incompatible with parental responsiveness. Bystrova et al (Bystrova, Ivanova et al. 2009) found that infants swaddled during the newborn period received less positive affective participation and less mutuality and reciprocity with their mothers. These striking findings reflect earlier concerns of anthropologist Ruth Benedict (Benedict 1949) who criticized what she termed "the relative impersonality of swaddling" (p345). In sum, swaddling creates a sub-optimal interactive style in mothers and infants, objectively measured by dyadic mutuality. The intervention may produce complex relational outcomes for mother and infant.

Part Nine: Swaddling and Physical Development

Few contemporary studies have examined the impact of swaddling on physical development. This research deficit may reflect the commitment and resources needed to conduct longitudinal enquiry. From the small pool of available literature, two aspects of swaddling may impact on this area of development: technique and duration.

Swaddle Technique

There is clear correlation between swaddling and risk of developmental dysplasia of the hip (DDH) (Loder and Skopelja 2011). This neonatal condition occurs when the 'ball and socket' joint of the hip does not properly form. Harcke, Karatas et al. (Harcke, Karatas et al. 2016) demonstrated that swaddling limited hip flexion/abduction and even dislocated one infant's unstable hip. However, defenders of swaddling argue that reports of DDH disproportionately arise in cultures which apply swaddle techniques that are tight around the hips, such as in Turkey (Kutlu, Memik et al. 1992, Akman, Korkmaz et al. 2007, Dogruel, Atalar et al. 2008, Guner, Guner et al. 2013), Saudi Arabia (Abd El-Kader Shaheen 1989, Kremli, Alshahid et al. 2003), and Japan (Ishida 1977), and in cultures using the straight-legged swaddle wrapping technique, a mummy-like configuration well known to stress the hips (van Sleuwen, Engelberts et al. 2007). These cultures are excluded by the World Health Organization when drafting standards of motor achievement (de Onis, Garza et al. 2004).

The dominant and enduring view of the 1960s that swaddling only increased risk of DDH in infants who are genetically predisposed (Salter 1968), was superseded by a recent appreciation of inherent risk. The American Academy of Paediatrics assert that swaddling should "allow room for movement around the hips and knees" (Moon and Task Force On Sudden Infant Death 2016)(p7). The American Academy of Orthopaedic Surgeons and International Hip Dysplasia Institute (IHDI 2020) reiterate that parents who want to swaddle should practice "hip-healthy swaddling", a technique that allows the infant's legs "to bend up and out at the hips" and not "tightly wrapped straight down and pressed together" (IHDI 2020). Yet despite explicit policy guidelines, the risk of hip dysplasia concurrent with swaddling is seldom acknowledged or counselled by contemporary health professionals[6].

Swaddle Duration

Interrelated with swaddle technique is the factor of duration. It is unclear how chronic immobilization may affect physical development. Research conducted in the 1940s regarding the attainment of motor milestones found no evidence to suggest that swaddling has short-term or long-term effects (Leighton and Kluckhohn 1947, Dennis and Dennis 1991, Chisholm and Cary 2009). In an ethnographic study of Hopi Indian children, those swaddled tightly using a cradle board technique for three months were no slower to walk than swaddled infants whose carers did not use a cradle board (Dennis and Dennis 1991).

Nonetheless, when adults are rendered immobile for prolonged periods, they experience muscle wasting (Appell 1990). This phenomenon is caused primarily by declines in muscle protein synthesis. Despite the relative difference between adult and infant mobility and weight-bearing, it is possible a similar dynamic may impact the developing muscles of the infant. Current guidelines recommend that parents who wish to swaddle should do so for every sleep (The Lullaby Trust 2020). This translates into around 70% of time spent under motor restraint (So, Adamson et al. 2007). Being placed supine at all times, although the only safe position for swaddled infants, discourages neck rotation and delimits the development of gross motor skills (Hewitt, Kerr et al. 2020).

The effects of prolonged reduction in mobility may also reach into unswaddled periods. Citing past clinical work (Gerard, Harris et al. 2002), Narangerel and colleagues (Narangerel, Pollock et al. 2007) hypothesised that "Infants who are habituated to swaddling may move less in both swaddled and unswaddled conditions" (p263). Prolonged periods of skeletal muscle inactivity have led to rapid atrophy in critically ill infants. In one ultrasound study of infants on mechanical-ventilators, 41% lost thickness in limb muscles, occurring within just 5–7 days (Johnson, Ng et al. 2018). This percentage was likely underestimated due to difficulty detecting atrophy in the small muscles of infants via ultrasound (Johnson, Ng et al. 2018).

Apart from physical composition, changes in physical presentation have been noted in swaddled infants. The intervention has been linked with brachycephaly (symmetrical flattening of the bone area at the back of the skull). This condition results from the impact of gravity and persistent occipital mechanical pressure combined with the swaddled infant's inability to reposition itself (Graham 2006).

[6] see survey chapter.

In sum, the brevity of this section reflects diminished clinical interest in the impact of swaddling on physical development. Whether this is because swaddling does not inherently pose a risk to developmental outcomes is debatable. Existing research highlights aspects of swaddle technique and duration that may pose risk. Yet concerns that were presented in the past now appear historical relics, as highlighted by the dearth of literature and underscored by data from professional practice. This empirical tumbleweed is perhaps unsurprising considering the relative difficulty, in longitudinal terms, of studying development. Nonetheless, the variables of this topic, as primarily measurable biological outcomes, lend themselves to comparison within and across populations. As well as researching the impact of lengthy swaddle duration, inquiry should determine an objective threshold of acceptable swaddle tightness that acknowledges diversity in swaddle technique and duration.

Concluding Remarks

Table 3 Summary of conclusions

Review topic	Key conclusions
Sleep	Most data show that, relative to unswaddled infants, swaddled infants sleep longer per day. However, these effects seem reliant upon infant naivety to swaddling. The impact of such prolonged sleep is unclear. Further, evidence of the effect of swaddling upon sleep states is conflicted, with some studies showing greater Quiet Sleep whilst swaddled, and others showing greater Active Sleep whilst swaddled. Independent variables such as feeding mode, delivery mode, and prior experience of swaddling, are seldom distinguished in the literature.
Arousal	The effect of swaddling upon infant arousal is contested. The Movement Hypothesis posits a fundamental role of movement within the arousal process in which arousal is stifled by swaddling. Conversely, the Overload Hypothesis posits that the constant tactile stimulation of swaddling 'drowns out' competing stimuli thereby raising the sensory threshold for arousal. In contrast, there is limited research to suggest that swaddled infants are more sensitive to stimuli, The Enhancement Hypothesis.
The Nervous System	There is a possible link between motor restraint and a 'freeze or shutdown' stress response, as illustrated by Polyvagal Theory and measured by Heart Rate Variability. Most studies demonstrating this link employ animal participants. Very little research of the stress response has involved human infants, and those that have done so, produced conflicting results.
The Respiratory System	When swaddled, infants show increased respiratory frequency linear with the tightness of the swaddle. There is currently no definitive evidence linking swaddling to increased respiratory infections.
The Thermoregulatory System	It appears that swaddling protects against heat loss in premature and VLBW infants but is by no means of conclusive benefit to healthy full-term infants.
Feeding	The influence of swaddling upon feeding is unclear. Evidence associates swaddling with a reduction in feed frequency. The intervention poses a visual barrier to infant feeding cues, as well as prohibiting skin-to-skin contact and

	delimiting infant hand movement - natural features of the breastfeeding process. Given the importance of regular feeds, particularly for breastfed infants, the prolonged sleep associated with swaddling may be problematic.
Cognitive Development	A small pool of evidence suggests that restricted limb movement through swaddling may enhance the intake of new information. While swaddled, both premature and term infants are shown to spend more time demonstrating sustained visual attention on a novel item (e.g., a shape or lighted panel).
Social Development	Given that swaddling visually obscures infant cue-giving, scholars have suggested that routine use of the intervention interferes with maternal responsiveness. In this respect, several studies have shown swaddling to correlate with reduced reciprocal interactions between mother and infant.
Physical Development	There is strong evidence for an association between straight-legged swaddling and increased risk of developmental dysplasia of the hip (DDH). Currently, no data suggest that swaddling with legs bend up and out at the hips (hip-healthy swaddling) has any adverse effects on hip development. On the other hand, the intervention has been linked with brachycephaly (symmetrical flattening of the bone area at the back of the skull).

Infancy is a critical window of development, during which certain factors of the social and physical environment can either promote or impede development. In industrialized cultures, swaddling is symbolic of the compartmentalization of mothers and infants as separate individuals. Yet, biologically, mothers and infants are mutually-regulating physiological systems. Swaddling, a parental behaviour with direct impact on infants, is surprisingly under-researched beyond its interaction with immediate sleep architecture. Literature is characterised by an over reliance on the biomedical model, with scholars generously investigating some topics but neglecting others. Data gleaned via this approach are presented for a medically minded audience and seek to validate swaddling as a prescriptive, albeit non-pharmacological, intervention. While some constructs have been analysed in moderate detail (i.e., sleep length), there are still many areas that have not been fully and thoroughly explored and deserve further attention (i.e. sleep cycle, cognition, social and physical development).

Nonetheless, when maverick voices such as Mohrbacher, Fauntleroy, and Bergman, are highlighted, a complex and cautionary picture emerges (Mohrbacher 2010, Fauntleroy 2012, Bergman 2014). This more holistic view positions swaddling as producing maternal deprivation with developmental implications. A common thread running through this emerging narrative refers to the potential of swaddling to influence the body's homeostatic system, and thus an infant's ability to adjust to internal and external physiological changes. In this context, falling asleep and staying asleep may serve a defensive behavioural response to the biological challenges induced by swaddling. The swaddled infant appears somnolent, as described in the introductory quote, and from observation, possibly content. However, reliance on observation alone is reductive. The biological and the behavioural form a deeply complex, integrated matrix of interlocking systems.

Mothers and infants share a symbiotic relationship across these biobehavioural systems. Triggering of one system via for instance, stress (the nervous system), impacts other systems such as breathing (respiratory system) and temperature (thermoregulatory system). These biological interactions produce measurable behavioural outcomes in sleep, feeding and arousal. As a critical time-window in ontogeny, biobehavioural outcomes during infancy create set points that influence the trajectory of social, cognitive and physical development.

This review has combined critical epidemiological, ethological and biological perspectives to inspire novel theories concerning the intersections of biology and behaviour. These hypotheses seek to reconceptualize the standard narrative on swaddling.

Chapter 5. Swaddling: a clinical review.

> *"Although I don't mention swaddling as part of my baby-care classes because it's not a core skill, parents always bring it up - it's very fashionable at the moment"*
>
> Midwife, London, UK (as cited in Blundell 2013).

The literature review will now shift from theoretical and laboratory knowledge of mother-infant dyads to the monitoring and treatment of dyads as patients of the health care system. The overall goals of the review is to first evaluate the current clinical context of swaddling and then to answer the question: To what degree is swaddling health-promoting or health-harming? Within this vein, recent developments in clinical practice are discussed.

Clinical Guidelines

> *"First we nursed our babies; then science told us not to.*
> *Now it tells us we were right in the first place.*
> *Or were we wrong then but would be right now?"*
> (Williams 2012)(p157).

Clinical guidelines can be considered as the offspring of biomedicalized infant care. They set authoritative standards for what is considered 'normal' and 'healthy' by the Western paediatric paradigm (McKenna, Ball et al. 2007, Ball 2008, Tomori 2014). One topic in particular - infant sleep - was increasingly brought under scrutiny over the past century as an object of surveillance (Wolf-Meyer 2012, Tomori 2014). Anthropological critiques of clinical guidelines on infant sleep note they arise from and reproduce Western cultural ideologies that are informed by moral judgement of the parent–child interrelationship (Ball 2017). In 1997, the WHO spoke of "an epidemic of guidelines" inundating health services (World Health Organization 1997)(p1). They critiqued that few of these guidelines were explicit and evidence-based, and fewer still had planned dissemination, implementation and evaluation strategies.

A primary driver of guideline development is the United States, as a result of rapid growth in health care costs (World Health Organization 1997). Yet, despite a plethora of published infant-care guidelines, there remain no consolidated recommendations for swaddling. Most medical organizations, including the National Health Service in the UK, the Canadian Paediatric Society, the American Academy of Paediatrics (AAP), and the WHO, have refrained from providing definitive guidelines concerning the intervention. This may be because there are more studies showing that swaddling is effective at promoting sleep than there are asking whether or not this is desirable.

Swaddling as Medicinal

To ascertain the degree to which guidelines and related policy should promote or penalise swaddling, it is important to consider the intervention's medicinal (i.e. healing or curative) value. To what extent does swaddling play a role in *promoting* health? This section of the review will aim to answer that question by detailing six medicinal uses of swaddling.

Postnatal depression

Maternal mental health disorders (MMHDs) are shown to affect 1 in 7 women and have long-lasting implications for both mother, infant and the health care economy (Weissman, Berry et al. 2016, Luca, Garlow et al. 2019). In the U.S., current emphasis has turned to prevention of these disorders rather than cure. The United States Preventive Services Task Force recommends that clinicians provide or refer women who are at an increased risk of postnatal depression (PND) to training interventions, such as counselling, expressive writing, and infant sleep training (Force, Curry et al. 2019). Numerous studies, both historical and contemporary, suggest that swaddling may be a valid tool in this process (Hunziker and Barr 1986, Pinilla and Birch 1993, van Sleuwen, Engelberts et al. 2007). This approach to maternal mental health is novel given that most interventions to prevent PND have focused on the mother rather than the mother–infant dyad (Werner, Gustafsson et al. 2016).

Recently, an American efficacy trial of 60 impoverished pregnant women tested swaddling as part of "a novel dyadic intervention" (Scorza, Monk et al. 2020)(p100230). In line with a robust existing evidence base, the intervention significantly reduced postnatal depressive and anxiety symptoms at 6 weeks. The authors concluded that parenting tools that enhance maternal confidence and potentially facilitate infant regulation are effective preventative measures for PND. Likewise a recent Japanese randomized controlled trial (RCT), produced similar results (Doi, Fujiwara et al. 2020), and a systematic review of RCTs on the topic reiterated those findings (Scorza, Monk et al. 2020).

One likely mechanism involved in such positive outcomes hinges on the association between reduction in crying duration and swaddling. 'Excessive crying' is strongly associated with PND (Petzoldt 2018) and swaddling has shown to significantly reduce crying by around 10 minutes per day in such infants (Day 2015, Demirel, Egri et al. 2018, Moller, de Vente et al. 2019, Doi, Fujiwara et al. 2020). Insufficient or poor-quality maternal sleep is also associated with PND (Tjoa, Pare et al. 2010, Zhai, Zhang et al. 2015), and increasing infant sleep efficiency through swaddling may tackle this problem. The intervention is associated with greater sleep continuity and fewer awakenings (van Sleuwen and L'Hoir 2007, Dixley 2015), and is considered a strategy to promote independent infant settling (Werner, Gustafsson et al. 2016).

Pain management

Despite inconsistent evidence, swaddling is commonly performed in clinical settings as a "comfort measure" to mitigate infant pain (Maroney 2003)(p682). The Association of Paediatric Anaesthetists guideline regarding good practice in postoperative and procedural pain recommend swaddling during vaccinations (Howard, Carter et al. 2008), along with the

WHO guidelines on drawing blood (World Health Organization 2010) and the AAP (American Academy of Pediatrics 2000). Yet, an early study of interventions to decrease procedural pain concluded that pacifiers were more effective than swaddling (Campos 1989) and another found swaddling had no significant effect (Wisdorf-Houtkooper 1997). In contrast, a number of later studies have shown swaddling to be as effective as breastfeeding and kangaroo mother care at managing infant pain (Hashemi, Taheri et al. 2016, Fallah, Naserzadeh et al. 2017). In 2004, Hung and colleagues observed the pain responses of infants undergoing a heel stick procedure (a routine medical procedure in which the heel of an infant is punctured to obtain a small amount of capillary blood for use in laboratory tests)(Huang, Tung et al. 2004); Infants who were swaddled returned to their baseline heart rates and oxygen saturation values in shorter periods of time with lower scores of pain response compared to infants that were merely 'contained' (held by a caregiver), an outcome that was mirrored by a later study (Morrow, Hidinger et al. 2010). Around this time, a review of systematic reviews on pain interventions and an additional randomized controlled trial of healthy infants undergoing routine heel stick procedures cemented swaddling as an effective non-pharmacological strategy for procedural pain (Yamada, Stinson et al. 2008, Shu, Lee et al. 2014). Interestingly, in 2011, a meta-analysis concluded there was a good enough evidence base to support swaddling to mediate pain in preterm but not in full-term infants (Pillai Riddell, Racine et al. 2011). More recently, Inal and colleagues observed infants undergoing a heel stick procedure and found that, although swaddling was associated with reduced pain responses relative to the control group, maternal holding was associated with the lowest pain responses (Inal, Aydin Yilmaz et al. 2021).

Discord in outcomes may be related to the fact that the exact pain-relieving mechanism of swaddling is unclear. Scholars have hypothesised it to be rooted in the act of sensory stimulation or in ‘sensory distraction’ (Efe, Dikmen et al. 2013, Villacres and Chumpitazi 2018). Others have attributed the pain-relieving properties of to the intervention’s utility as 'deep pressure input', (Chen, Yang et al. 2016). This type of tactile pressure stimulation is believed to normalize physiological arousal resulting from stress. According to this view, due to a reduction in body movements, the overall number of reactive stimuli in tissues, the spinal cord, the thalamus and the cerebral cortex is reduced (Mohammed-Lecturer and Ahmed 2018).

Discrepancies regarding the utility of swaddling for pain relief may also be methodological in origin. The ‘pain scales’ that researchers and physicians apply to determine infants' experience of various medical procedures commonly feature the criterion 'movement of the extremities' to signal a pain response. This is problematic during swaddling as despite the outward appearance of less activity, muscles continue to contract microscopically in response to a painful stimulus and these signals continue to be sent to the brain (Holsti and Grunau 2007, Oatis 2009). The scenario of swaddling therefore highlights the importance of measuring both behavioural and physiological reactions during painful procedures and of being mindful when combining such criterions.

Medical procedures

In addition to its application for the purposes of pain-relief, swaddling is routinely applied in the context of clinical diagnostics. For instance, in procedures such as CT, MRI or bone scans, movement artifacts can affect the reliability of results. Traditionally, clinicians have used sedation or general anaesthesia to combat this problem; however, around the turn of the millennium, concerns about neurotoxicity resulted in a shift to swaddling (Neu and Browne 1997, Mathur, Neil et al. 2008, Golan, Marco et al. 2011). In 2016, of 96 clinics surveyed in the U.S., 'feed and swaddle' was the primary method of preparation for medical procedures (Heller, Yudkowitz et al. 2017). That swaddling is the preferred method of clinical motor restraint was enshrined as an NHS guidelines in 2018 (NHS England 2018) and AAP guidelines in 2019 (Krowchuk, Frieden et al. 2019).

Neonatal Abstinence Syndrome

Neonatal abstinence syndrome (NAS) occurs when a foetus is exposed to opioid drugs. Infants with NAS experience withdrawal upon termination of placental opioid supply following birth. Common symptoms include restlessness, tremors, agitation and gastrointestinal disturbances (Ryan, Dooley et al. 2019). The past decade has seen a sharp increase in the incidence of NAS (Patrick, Schumacher, et al, 2012, as cited in McQueen and Murphy-Oikonen 2016) attributed to the more liberal prescription of opioids for pain control in pregnant women (Ailes, Dawson, et al, 2015; Yazdy, Desai and Brogly 2015; Warren, Miller, et al, 2013, as cited in McQueen and Murphy-Oikonen 2016) and to the illicit use of opioids (Cicero, Ellis and Harney 2015; Gomes and Juurlink, 2016, as cited in McQueen and Murphy-Oikonen 2016).

The WHO and the AAP have recommended swaddling as a first-line strategy for managing NAS (Hudak, Tan et al. 2012, World Health Organization 2014). They label the quality of underlying evidence "Low" but maintain the strength of the recommendation "strong". This is because the benefits of swaddling in this scenario are believed to strongly outweigh any potential harms (World Health Organization 2014)(p17). Swaddling is thought effective in combination with pharmacotherapy for severe NAS, or as stand-alone therapy for less severe NAS (CADTH 2017, Ryan, Dooley et al. 2019). In a 2014 systematic review of NAS treatments, 11 of the 20 journal articles recommended swaddling as an effective therapeutical intervention (MacMullen, Dulski et al. 2014). A more recent systematic review and meta-analysis affirmed this finding (MacMillan, Rendon et al. 2018). Used in 95% of clinical settings (Mehta, Forbes and Kuppala 2012, as cited in Mangat, Schmölzer et al. 2019), swaddling is shown to reduce the need for pharmacological therapy (opioids and/or sedatives), decrease length of clinical stay, and support breastfeeding in this infant population (Pritham 2013). Regarding the latter, swaddling enhances the breastfeeding experience, reassuring the mother and assisting the infant:

"The infant's communication, particularly breast refusal, may be interpreted by the caregiver as a sign that the breastfeeding experience is aversive, when in fact the child is earnestly seeking deeper and more intense sensory input" (Weiss-Salinas and Williams 2001)(p146).

Considered a 'soothing technique', swaddling can maximize infant comfort by decreasing physiologic distress, improving motor organization, and promoting self-regulation (van Sleuwen, Engelberts et al. 2007). It is shown to decrease sensory stimulation "by creating boundaries and providing containment" (Moulsdale and Hermann 2008)(p127). When NAS necessitates a stay in NICU and thus separation of mother and infant, swaddling is one of the few available and effective management techniques (Cleveland 2020).

Colic

Infantile colic is a condition describing excessive crying[7] in an otherwise well infant. Although colic has no definitive cause, it is thought to be an exacerbation of normal infant crying brought about by physiological and psychosocial factors (Zeevenhooven, Koppen, and Benninga, 2017, as cited in Sung 2018). Thought to affect up to 40% of infants (Lucassen, Assendelft, van Eijk, et al. 2001, as cited in Johnson, Cocker et al. 2015), colic is adversely associated with maternal depression, child abuse and early cessation of breastfeeding (Vik, Grote, et al. 2009; Barr, 2012; Howard CR, Lanphear N, et al. 2006, as cited in Sung 2018). Mothers of colicky infants have reported it makes them feel insufficient (Radesky, Zuckerman, Silverstein, et al, 2013; Ellett and Swenson, 2005; Kurth, Kennedy, Spichiger, et al, 2011, as cited in Didişen, Yavuz et al. 2020).

In the treatment of colic, scholars consider swaddling as "effective but possibly harmful" with reference given to the risk of hip problems (Sung 2018)(p107). Others maintain that swaddling has no significant benefit in this context (Johnson, Cocker et al. 2015). Straddling the two views, some have argued that swaddling can give mothers a sense of agency and help them to "feel that they are doing what they can" (Sparrow and Brazelton 2008)(p6).

Neonatal Intensive Care

Neonatal intensive care units (NICU) are situated within healthcare institutions and specialize in the care of sick infants. The most common patients of NICU are infants of low birth weight and those born prematurely, i.e., before 37 weeks gestation. Premature infants may spend several weeks or months in a NICU until their organs have developed enough to function without medical support. 60,000 infants are born prematurely in the UK each year (Tommys 2020). This clinical population tend to have weak muscle tone and decreased flexion in the limbs, trunk, and pelvis, and are unable to control their posture and movement (NHS England 2018). Being born prematurely can cause medical disorders including patterns of shoulder retraction, adduction of the hips, legs, and knees, increased activities of the lower extremities, difficulty regulating body temperature, anaemia, respiratory distress syndrome, lower muscle tone, and problems feeding due to an inability to suck or coordinate swallowing and breathing. Many medical problems of prematurity are believed related to absence of uterine conditions (Short, Brooks-Brunn et al. 1996).

The value of swaddling in the neonatal clinical context was originally espoused in the 1980s by Als and others (Als, Lawhon et al. 1986). Their research recommended firm and continuous containment to the infant limbs and trunk, arguing that containment was essential in assisting

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[7] Crying more than three hours of the day for more than three days of the week: Wessel, M. A., J. C. Cobb, E. B. Jackson, G. S. Harris and A. C. Detwiler (1954). "Paroxysmal fussing in infancy, sometimes called" colic"." Pediatrics **14**(5): 421-435.

the infant in the organization of alertness (Als, Lawhon et al. 1986). By 2006, swaddling was considered a Developmental Care Intervention (DCI) (Ramachandran and Dutta 2013), with 86% of American NICU patients routinely adopting this 'gentle' method of handling[8] and caregiving (Field, Hernandez-Reif et al. 2006). It is often assumed that NICU patients are especially responsive to womb-like sensations because of their immaturity (Moller, de Vente et al. 2019). The intervention is considered to provide numerous benefits for this clinical population. It is shown to promote more organized infant behaviour and regulate body temperature (Short 1998, Altimier and Phillips 2013), increase blood flow to the body tissues and the brain, improve oxygen saturation (Hockenberry and Wilson 2013), strengthen neuromuscular development (Short, Brooks-Brunn et al. 1996, Neu and Browne 1997, van Sleuwen, Engelberts et al. 2007), reduce distress (Neu and Browne 1997, Ohgi, Akiyama et al. 2004, Mohammed-Lecturer and Ahmed 2018), and improve cognitive development (Lejeune, Delacroix et al. 2021). In a randomized clinical trial of thirty preterm infants of 28 to 33 weeks' gestational age, those swaddled during handling showed significantly better neurobehavioral functioning at 2 weeks' corrected age. Outcomes included better motor system function and self-regulation as well improved state stability, intensity, and threshold of responsiveness (McCall, Alderdice et al. 2018).

In the context of hypotonic infants (those with abnormally low muscle tone), the application of "judicious, short-term swaddling" may promote feeding by helping them to use their tongue and jaw more effectively (Genna 2016)(p322). In line with this, the Irish Neonatal Health Alliance in their 2019 booklet for parents, 'From Surviving to Thriving: Oral Feeding Success on the Neonatal Unit and Beyond' urges parents of premature infants that have been having trouble feeding to consider swaddling (Heffernan 2019). The resource advises that, "swaddling can help to keep the baby in the calm but alert state that is ideal for oral feeding attempts" (p10).

In summary, swaddling can be beneficial as a short-lived-duration intervention for specific purposes (e.g., pain management, medical procedures) in all young infants. The intervention can also be beneficial as a short-lived-duration intervention for specific purposes (e.g., sensory organisation) in specific infants (NICU patients), and as a moderate-duration intervention for a specific purpose (e.g., 'soothing') in specific infants (e.g., those with NAS or colic).

Swaddling as Inimical

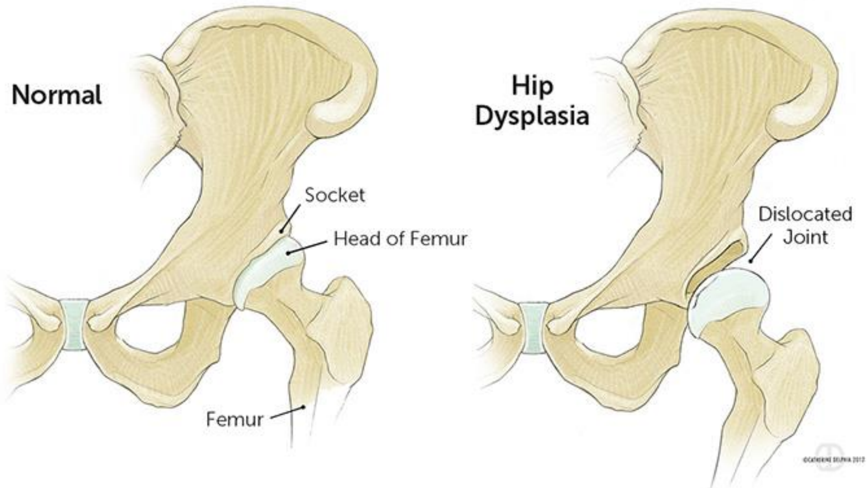
[8] Sleep disruption caused by even routine handling of neonates can lead to poor brain maturation {De Beritto, 2020 #1948}.

On the other side of the swaddling debate is the view of swaddling as detrimental or damaging to infant health. Concerns around hip dysplasia and the breastfeeding of full-term infants dominate the most robust evidence supporting this view.

Hip dysplasia

Developmental Dysplasia of the Hip (DDH) occurs when the 'ball and socket' joint of the hip does not form properly. A compelling evidence-base associates the condition with excessively tight swaddling (Loder and Skopelja 2011, Harcke, Karatas et al. 2016) and with swaddling the legs in a straight position (van Sleuwen, Engelberts et al. 2007). Acknowledging an inherent risk, the AAP assert that swaddling should "allow room for movement around the hips and knees" (Task Force On Sudden Infant Death 2016)(p7). The American Academy of Orthopaedic Surgeons and International Hip Dysplasia Institute (IHDI 2020) reiterate that parents who want to swaddle should practice "hip-healthy swaddling", a technique that allows the infant's legs "to bend up and out at the hips" and not "tightly wrapped straight down and pressed together" (IHDI 2020).

Figure 7 The Anatomy of Hip Dysplasia (Orthoinfo 2021)



Despite explicit guidelines, the risk of hip dysplasia concurrent with swaddling is inconsistently acknowledged or counselled by contemporary health professionals[9]. This is particularly worrying given a contemporary culture of contradiction across both lay and medical discourse. For instance, a popular American physician-author has warned parents that "loose swaddling will actually make fussy babies more upset" and suggested that the tighter the swaddle the better the calming effects on infants (Karp 2002, Karp 2004)(p103) and the AAP have warned that loose swaddling could result in asphyxiation or strangulation

[9] see survey chapter.

(Task Force On Sudden Infant Death 2016). Contradictions between the desirability of tight versus loose swaddling undermine health promotion efforts, yet an optimum degree of tightness remains unspecified[10].

Commented [BHL1]: In footnote below indicate chapter name and relevant pages the reader should refer to

Breastfeeding

In the U.S., swaddling immediately after delivery is performed as 'routine care'. Newborns are typically swaddled before being placed in bassinets by their mother's bed or in the hospital nursery (Mohrbacher 2011). In such settings, the practice is believed to promote work efficiency of clinical staff (Ahn, Yang et al. 2020). Yet adversely, infants swaddled during their first two hours of life show delayed feeding behaviours, suckled less at their first breastfeeding, and established breastfeeding later (Moore and Anderson 2007, Cleveland, Hill et al. 2017, Safari, Saeed et al. 2018). Some argue that swaddling cultivates newborn behaviour that is more stoic and less investigative (Brackbill 1975). The intervention is associated with decreased infant wakefulness during breastfeeding 4 days after birth and rougher maternal affective interaction (Dumas, Lepage et al. 2013), and with a decrease in the demonstration of infant feeding cues (Jansson, Mustafa et al. 1995, Moore and Anderson 2007). One study explored this dynamic in detail. Bystrova and colleagues observed the feeding behaviours of swaddled and unswaddled infants who were taken to the nursery for the first two hours of life and then returned to their mothers for the rest of the hospital stay (Bystrova, Widstrom et al. 2007). The researchers found that swaddled infants had significantly greater weight loss on their third and fifth days of life. This finding highlights the importance of the immediate postnatal period and the detriment of mother-infant separation.

In contrast to swaddling, a study of 21,842 newborns found a linear correlation between the length of time mothers and infants spend in skin-to-skin contact during the first three hours after birth and the likelihood of exclusively breastfeeding at hospital discharge (Bramson, Lee et al. 2010). Indeed, if an infant is placed tummy-down on their mother's body immediately after delivery, they will make their way to her breast. When given the time to perform this crawling manoeuvre, the infant's touch and movements increase maternal oxytocin which aids milk production and postnatal recovery (Matthiesen, Ransjo-Arvidson et al. 2001). On the other hand, scholars have argued that while restrained in a swaddle, newborn infants may struggle to achieve a suitable latch; Those tightly swaddled may have inadequate neck flexion to facilitate the suck/swallow/breathe sequence necessary for nursing (Boles 2017).

Acknowledging this evidence base, Unicef Baby Friendly guidance state that early skin-to-skin contact should continue until the end of the first successful breastfeed "to enhance the infant's adaptation to life outside of the womb" (Unicef 2020)(p64). This guidance underscores the standard aimed for by the majority of UK maternity units (91%) and health visiting services (89%) that are working towards Baby Friendly accreditation (Unicef 2020). To achieve full accreditation, health services must "support all mothers and babies to initiate a close relationship and feeding soon after birth" and "enable mothers to get breastfeeding off to a good start" (Unicef 2013). The organisation remains silent on the topic of swaddling.

[10] see sensor chapter.

The Hottest of Topics: SIDS and Swaddling, Medicinal or Inimical?

"…observed to reduce sleep-related infant movements and promote more uninterrupted deeper sleep (a cultural goal of infant care)" (McKenna, Ball et al. 2007)(p135).

The reader would be forgiven for assuming the above quotation describes swaddling, given the characteristics outlined. The quotation in fact describes the effects of placing an infant in the prone position for sleep, a practice that, although common throughout the 1970s and 1980s, has since been associated with infant death (Kahn, Sawaguchi et al. 2002). It is no secret that the physiological effects described equally mirror those of swaddling. Such outcomes are increasingly celebrated as the hallmarks of a 'good' baby in WEIRD societies (Ball, Tomori et al. 2019).

Infant death in the sleep environment is known as Sudden Unexpected Death in Infancy (Ramachandran and Dutta 2013). This clinical term encompasses sudden infant death syndrome (SIDS) as well as other causes such as accidental suffocation and strangulation in bed, sudden onset illnesses, and homicide (Altfeld, Peacock et al. 2017). In the UK, around 230 infants die with a SIDS label every year. Of these deaths, 88 per cent happen within the first 6 months of life (The Lullaby Trust 2020). Specifically, SIDS is defined as a sudden unexplained death of an infant where no cause is found after detailed post-mortem. It is a leading cause of postnatal infant mortality in the UK (Garstang and Pease 2018) and US (Freudigman and Thoman 1993) and therefore a critical factor in the policy development of many Governmental and non-Governmental organisations.

Scholars and policy makers have argued that sleep interventions such as swaddling, which promote long periods of consolidated sleep, may be treacherous for infants with deficient arousal mechanisms (Mosko, Richard et al. 1996, Mosko, Richard et al. 1997, The Lullaby Trust 2013). Yet, whether swaddling reduces or exacerbates risk of SIDS remains a highly contentious topic. In the UK, The Lullaby Trust, a charitable organisation promoting infant health, maintain that "further evidence is still required before a firm recommendation can be made on swaddling" (The Lullaby Trust 2019)(p30). Similarly, in the U.S. the AAP cite the evidence deficit as the reason why they cannot formally recommend swaddling but nonetheless recognise the intervention is a useful method to calm infants and to promote sleep (Jana and Shu 2005). In a retrospective review of SIDS cases, 22 deaths involved swaddling. However, only one of those was not related to environmental risks such as blankets, pillows, and bumper pads (McDonnell and Moon 2014). In the UK, the Lullaby Trust identifies swaddling as a "factor in need of further research" (The Lullaby Trust 2019)(p1), while an NHS review cites swaddling as having a "suggested emerging association with SIDS" (NHS England 2019)(p13).

To date, number of swaddle studies is small, degree of variability between studies is high, and most have failed to identify crucial variables such as sleep position, feed type and habituation to swaddling. Based on this nebulous knowledgebase, AAP guidelines state there is "no evidence to recommend swaddling as a risk reduction strategy for SIDS" (CADTH 2020)(p4).

Using the Strength of Recommendation Taxonomy (SORT), the AAP graded this guideline with a strength of 'Level C' (Task Force On Sudden Infant Death 2016). The SORT is a three-tier taxonomy centring on the quality, quantity, and consistency of evidence: "An A-level recommendation is based on consistent and good-quality patient-oriented evidence; a B-level recommendation is based on inconsistent or limited-quality patient-oriented evidence; and a C-level recommendation is based on consensus, usual practice, opinion, disease-oriented evidence, or case series for studies of diagnosis, treatment, prevention, or screening" (Ebell, Siwek et al. 2004). Recommendations graded C are therefore weakest in strength.

Despite the AAP stance, some studies have associated swaddling with a slight reduction in SIDS risk (odd ratio 0.64–0.69) (Franco, Raoux et al. 2013), and the intervention is associated with several potential protective mechanisms. For instance, commercial swaddle wraps that transcend the traditional sheet of material and comprise of an array of features (Velcro, etc) may eliminate the risk associated with asphyxiation (McDonnell and Moon 2014). Inadvertent head covering can occur as a result of loose bedding in the infant's sleeping environment (Fleming, Azaz et al. 1992, Fleming, Levine et al. 1993, Blair, Mitchell et al. 2008) and swaddling may remove the need for such bedding (Cole, Young et al. 2020).

Additionally, swaddling may facilitate the protective supine position for sleep. Some infants appear to sleep poorly when placed supine. However, Gerard and others found that most infants tolerate this position when swaddled, even a significant number of those accustomed to sleeping prone (Gerard, Harris et al. 2002). Swaddled infants are thus more likely than unswaddled infants to be placed on their backs (Oden, Powell et al. 2012), and therefore have mothers that are more likely to adhere to safe-sleeping recommendations. In fact, a 1994 New Zealand study attempted to separate all possible circumstantial factors that contribute to SIDS and concluded that tight swaddling significantly *decreases* the risk of death (Wilson, Taylor et al. 1994). A later editorial on the topic of SIDS and swaddling concluded, "All in all, it would appear that the advantages of swaddling supine-sleeping infants outweigh the risks, if any" (Thach 2009)(p462).

In contrast, a meta-analysis of four case-control studies found that being swaddled supine was associated with "a small but significant risk" when compared with controls (Pease, Fleming et al. 2016)(p9). However, there were methodological limitations to this review including lack of uniformity in the prevalence of swaddling across studies, lack of a precise definition of swaddling, and inability to adjust for significant confounding factors associated with SIDS risk such as bed-sharing (Nelson 2017). UK guidelines clearly advise to remove swaddles for bed-sharing (The Lullaby Trust 2019, NHS Scotland 2020).

UK guidelines also advise to discontinue swaddling when the infant starts to roll (The Lullaby Trust 2019)(p30). In relation to this, results of a meta-analysis of four case-control studies judged to be of good quality based on the Newcastle-Ottawa Scale (Wells, Shea et al. 2018) found that risk of SIDS increases with age in swaddled infants, with the greatest risk posed to swaddled infants 6 months or older (Pease, Fleming et al. 2016). As infants age, their developing capacities increase situational dangers. The International Society for the Study and Prevention of Perinatal and Infant Death (ISPID) recommend that it is safest to swaddle infants from birth. The not-for-profit organization particularly warns against introducing swaddling at 3 months of age when SIDS risk is greatest (Horne 2020).

In a similar vein, the observation that swaddled infants have increased sleep length (Manaseki-Holland 2010) and decreased arousal frequency (Gerard, Harris et al. 2002) support the notion that sleep ecology has a sustained impact on arousability. Gerard and colleagues in their study of arousal, argued that the reduction in arousal seen in swaddled infants may prevent them from removing themselves from dangerous positions such as wedged, head-covered, or prone positions (Gerard, Harris et al. 2002). While asleep, young infants learn adaptive responses to physiological challenges (Tarullo, Balsam et al. 2011), such as how to respond to a respiratory obstruction (Harper 2001, Paluszynska, Harris et al. 2004). Until that learning is complete, they are endowed with an innate, brainstem-mediated sleep startle reflex of head lifting in reaction to such threat (McGraw 1963, Paluszynska, Harris et al. 2004). As detailed elsewhere in the literature review, swaddling suppresses these adaptive reflexes regardless of guidelines to 'swaddle correctly' (Task Force on Sudden Infant Death 2011, The Lullaby Trust 2019).

In summary, it cannot be definitively concluded that swaddling, independent of other factors, increases or decreases SIDS risk (see Table 4). Current views of the AAP Task Force on SIDS straddle the two extremes, maintaining that: "Although swaddling has not been shown to be a SIDS risk-reduction tool, there is no current evidence that suggests it should be contraindicated... when done properly, swaddling is still an important and appropriate tool in the care of the newborn" (Goodstein, Hauck et al. 2016). The knowledgebase is clear on a few specifics: that swaddled infants should only be placed supine and never over-wrapped. Further, caution should be given to wrap infants tight enough to reduce the risk of inadvertent head covering, although an optimum degree of tightness remains unspecified.

Table 4 Swaddling and SIDS Evidence Base

Increasing risk factors	**Decreasing risk factors**
When placed prone or on the side (The Lullaby Trust, 2019).	May promote protective supine position (Gerard et al., 2002).
With increasing infant age/development (Pease et al., 2016).	Commercial zip swaddles may reduce inadvertent head covering (McDonnell and Moon, 2014).
When introduced to older infants (Horne.R 2020).	May remove need for extra hazardous bedding (Cole et al., 2020).
When used in conjunction with other commercial interventions (McDonnell and Moon, 2014).	

Conclusion

The increasing dominance of Western biomedical conceptualizations continue to dictate expectations and guidelines for infant care, however the narrative lays silent on swaddling. This is because the full clinical impact of swaddling is yet to be determined. The purpose and duration of swaddling, along with the characteristics of the patient dyad, determine current clinical practice. However, this review has identified inconsistencies and tensions in the literature regarding both the health-promoting and health-harming facets of the intervention. Identifiable interacting (potentially modifiable) factors are emerging in the literature (e.g., infant crying and maternal PND; pain measurement methodology and perceptions of pain management) which may provide a compass for future research efforts.

Chapter 6. How robust is videosomnography for assessing infant sleep, and how do video-studies of infant sleep vary? A systematic review.

Introduction

> *"Headway can be made when the major players [of infant sleep research] face the multi-faceted complexities of this parenting practice and honestly appraise the methodology with which they aim to relieve the burden of evidence" (Mileva-Seitz, Bakermans-Kranenburg et al. 2017)(p17).*

In this quote, Mileva-Seitz and colleagues call for a cross-discipline merging of minds (Psycho-Anthro-Pediatrics) and a more critical approach to study design in order to enhance the field of infant sleep research. For my original research study based in the Durham Parent-Infant Sleep Lab I proposed to use videosomnography to quantify relevant aspects of mother -baby sleep. Prior to undertaking this study it was important to understand the advantages and disadvantages of this methodology. To do this I conducted a systematic review (SR) on the use of video methods for assessing infant sleep.

The role of sleep within infant and maternal wellbeing has grown in recognition over recent decades. Consequently, the issue of the most appropriate way to assess sleep has been elevated to the forefront of discourse (Galland, Meredith-Jones et al. 2016, Rudzik, Robinson-Smith et al. 2018, Tikotzky and Volkovich 2019, Del-Ponte, Xavier et al. 2020, Quante, Hong et al. 2020). Studies using video technology to facilitate sleep analysis date back to 1969 (Cabon, Porée et al. 2019). The methodology has surged in popularity as the cost of video equipment and production has declined (Jewitt 2012). Yet despite growing recognition of the potential of video as an investigative tool, this is the first systematic review to critically assess it as a methodological technique.

Review objectives

The SR aims to navigate the multifaceted landscape of video methods that have been used in infant sleep research. In doing so, the review aims to answer two questions:
1) How do video-studies of infant sleep vary?
2) How robust is videosomnography for assessing infant sleep?

From these objectives, three core concepts for the SR arise, as shown in Figure 8.

Figure 8 Core concepts derived from the research question.

Concept 1	Concept 2	Concept 3
Video	Infant	Sleep

Inclusion Criteria

- The review adopts an understanding of 'infant' as outlined by the World Health Organisation (2014): 'a child younger than one year of age.' This may include premature infants.
- The term 'video-studies' is interpreted as any primary source featuring video methodology, whether video was used as a primary or secondary data collection tool.
- 'Video data' is understood as 'a recording of moving pictures' (Cambridge English Dictionary 2018).
- Due to resource limitations, only English language sources are included.
- The review is limited to sources published from January 1991 to January 2021. Thirty years is cited as the ideal timeframe within which to explore video methodology (Luff and Heath 2012). Further, a preliminary scoping search suggested this timeframe would produce enough data to be comprehensive whilst staying relevant to contemporary video methodology.

Exclusion Criteria

- Studies unconcerned with assessing infant sleep. 'Assess' is defined as per Oxford English Dictionary definition as 'to calculate the amount or value of something'.
- Studies not incorporating video as a data capture method.
- Secondary sources.
- Non-English language sources.
- Data published outside the 1991-2021 timeframe.

Methodological Parameters

To address the review question effectively, both qualitative and quantitative studies were included (Mays, Roberts et al. 2001, Dixon-Woods, Agarwal et al. 2004, Harden 2010). This mixed-methods approach is a relatively new and growing methodology of systematic review (Harden and Thomas 2005). The approach is appropriate considering the present review question as video data can be generated and coded both descriptively and quantitatively.

To account for the possibility of insufficient indexing and database bias (Song 2000), eight major journals were hand-searched: *Journal of Clinical Sleep Medicine*; *Journal of Sleep Research*; *Pediatrics*; *The Journal of Pediatrics*; *Journal of Developmental & Behavioral Pediatrics*; *Sleep*; *Sleep Medicine*; *Journal of Sleep Research*. In addition, the reference lists of those studies which met the inclusion criteria were hand-searched, initially by title and then by abstract if deemed appropriate. After a search of grey literature sources, any relevant national and international conference data were requested, and key authors contacted when necessary to identify any missing papers. Authors were identified as key upon demonstrating a repeat presence in the field. This comprehensive approach acknowledges the standard that a review should utilise a minimum of two or more databases plus hand searching of selected journals (Suarez-Almazor, Belseck et al. 2000). When a study was duplicated across several publications, the papers were merged into one record for extraction and appraisal.

Search strategy

Search Strings

To systematically capture the most relevant data, the review adopted bespoke search strings. Figure 9 lists alternative terms for the core concepts listed in Figure 8. These terms were identified by scanning the titles and abstracts of retrieved articles of an initial scoping search and by using database thesauri and indexes where available.

Figure 9 Alternative terms for concepts in the review question.

Concept 1	Concept 2	Concept 3
"Video"	"Infant"	"Sleep"
"Film"	"Newborn"	
	"Neonate"	
	"Baby"	
	"Babies"	

The concepts (and their affiliated truncations) were used as search terms joined by appropriate Boolean operators. Parentheses were used to group clauses to form sub queries. Further, as some databases do not conduct automatic lemmatization (i.e. capturing singular and plural forms, and well as adjectives) an asterisk '*' was added to appropriate words. To achieve precision, titles were searched for the concepts 'infant' and 'sleep'. To achieve sensitivity and reflect the inclusion criteria's broad interpretation of 'video-studies' the concept of 'video' was searched within both title and abstract fields. Therefore, a typical search string looked as follows: **((*video*[Title/Abstract] OR film*[Title/Abstract]) AND (infan*[Title] OR newborn*[Title] OR neonate*[Title] OR baby[Title] OR babies[Title])) AND (*sleep*[Title])**

To account for Learning Effect and Fatigue Effect, a Pubmed database search was performed a second time after a significant period (6 months) had passed from the initial search. All new results were re-screened and newly published or previously overlooked papers were retrieved and screened, then assimilated into the review when appropriate.

Databases

The following databases were searched: Pubmed, CINHAL, PLoS and OpenGrey. These databases were chosen based on systematic review guidelines from The Joanna Briggs Institute (Peters, Godfrey et al. 2015), initial scoping exercises, the experiences of other researchers in the field, consultation with subject librarians and resource availability at the host institution Durham University. A grey literature database was included to capture unpublished records such as theses and conference proceedings. I chose OpenGrey as a more time efficient and systematic method of searching grey literature relative to hand searching.

Data Extraction

Given the relative novelty and rapid development of methodological reviews, there are no formally accepted extraction standards specific to the field. Rather, this review drew on video methodology publications to provide rich methodological detail, tailoring the extraction template for use with both qualitative and quantitative sources (Appendix 1). It incorporated elements of reporting standards for methodological reviews, the first pilot instrument for this field (Lawson, Colunga Lozano et al. 2019) and guidelines from The Joanna Briggs Institute (National Childbirth Trust 2015). Information was extracted for methodological aspects including setting variables (e.g., laboratory vs. home environment), procedural variables (e.g., camera operative, mode of data management), analytical variables (e.g., time/event sampling, coding scheme), and sample-related variables (e.g., sample size, sample socio-demographic and clinical characteristics). The selected variables aim to provide a sufficiently comprehensive picture of methods and procedures adopted in the literature. To ensure data extraction was methodical, impartial and reliable, all papers that meet the inclusion criteria were read in full and data extracted by hand using a customized data extraction template (Appendix 1). The template incorporated the following SPIDER formation for data extraction, believed to be an effective tool for mixed-methods reviews (Cooke, Smith et al. 2012).

Figure 10 The SPIDER formation for data extraction.

S	**PI**	**D**	**E**	**R**
Sample	Phenomenon of Interest	Design	Evaluation	Research type

Appraisal protocol

Some of the most-cited systematic reviews on the topic of infant sleep do not offer a critical appraisal of the included studies. To improve upon this, the review used the Mixed Methods Appraisal Tool (MMAT) (Appendix 2). The MMAT is a checklist designed for the appraisal stage of systematic mixed studies reviews (Pace, Pluye et al. 2012). It uses a ratings format which ultimately enables the reviewer to fashion an overall robustness score for each study. I have termed this overall robustness classification as “Risk of bias”. I chose the MMAT over the traditional Cochrane assessment (Higgins, Thomas et al. 2019), because the latter is designed primarily for Randomised Controlled Trials.

Flow diagram

As recommended by the Preferred Reporting Items for Systematic reviews and Meta-Analyses (PRISMA) (Moher, Liberati et al. 2009), each stage of the review process is presented in the flow diagram (Figure 11).

Figure 11 PRISMA flow diagram.

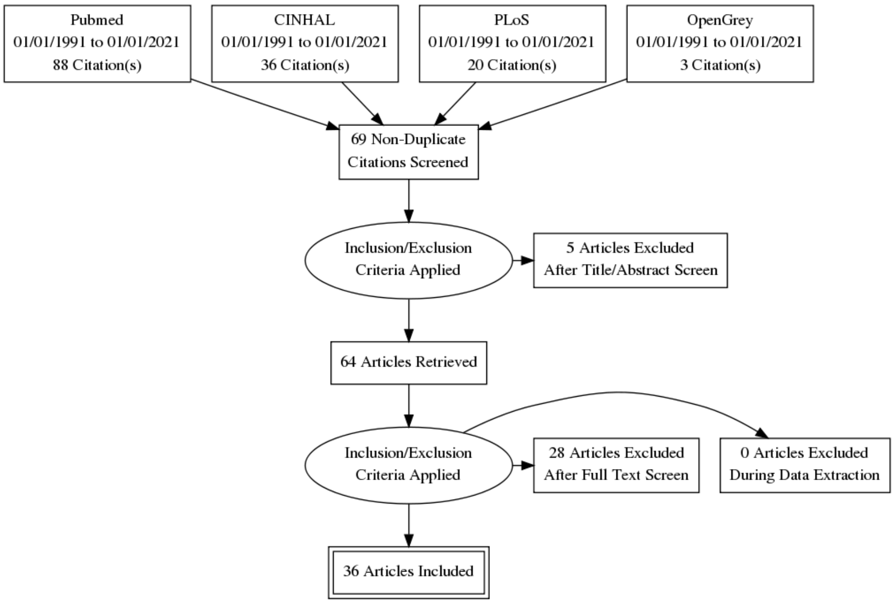


Figure 11 indicates the search strategy was successful at balancing sensitivity with precision. For example, the first database searched using the strategy (Pubmed) returned 88 records, of which 59 were excluded for failing to meet the inclusion criteria. More exclusions than inclusions suggest robust sensitivity whilst the manageability of the results indicates precision.

Narrative synthesis

Narrative synthesis is the most common synthesis method used in systematic reviews of public health (Campbell, Katikireddi et al. 2019). Yet despite this, there is limited guidance on correct protocol. This review will employ the high level framework recommended by the funding body, the ESRC (Popay, Roberts et al. 2006). Firstly, a preliminary synthesis of the included studies is presented, then to explore relationships within the data, an analysis of the review questions will follow. Finally, the robustness of the synthesis is critiqued.

Theory building and theory testing is considered a neglected aspect of systematic reviews, despite reviews being much more powerful than single studies for these purposes (Campbell, Katikireddi et al. 2019). To address this deficit, an underlying hypothesis is presented as follows: Video methodology can either increase or decrease risk of bias depending on the manner of its incorporation and its appropriateness to the study aims. Relative to other methods of assessing infant sleep, video methodology is more prone to 'unacceptability bias' and attrition due to the intrusive nature of the methodology.

Preliminary synthesis

After setting the date restriction and employing the search terms, a total 246 studies were retrieved. From this total, studies were discarded for their inability to meet the inclusion criteria. 180 were discarded at title. A further 5 were discarded at abstract, and a further 28 were discarded at full text. This left a total of 36 studies that met the inclusion criteria. All were integrated into the synthesis, thus ensuring that important insights were not excluded. For ease of discussion each study is numbered in square brackets [ ] and cited in text as such. This numbering format of presentation was chosen to enhance readability, a particularly important consideration when very large groups of studies are cited at once.

Review Question 1. How do video-studies of infant sleep vary?

Table 5 Summary of findings

Study details	Synopsis	Camera details	Design	Appraisal
[1] (Anders, Halpern et al. 1992). Sample: "21 normal, full-term first born infants" studied at 3 weeks and 3 months of age. Setting: Home. Outcome variable: Sleep-wake state organization. Funding: Not stated.	Sought to "examine falling asleep and night waking in infants during the first 8 months of life." Studied infants at 3 weeks and 3 months of age. Data examined at both cross-sectional (age group) and longitudinal (individual) perspectives. Recording length: 2 nights (not consecutive), "all-night".	One time-lapse video camera with a wide-angle lens. Camera position: placed on a tripod overlooking the crib. A microphone to record vocalization is attached to the camera. An infrared light (positioning not stated). Mothers activated the system before putting their baby to sleep and turn it off in the morning.	Deductive; Qualitative & quantitative; Triangulation of methodologies (telephone interviews); Cross-sectional; Longitudinal.	Strengths: Incorporated inter-rater reliability (Scores were "better than 85%"). Risk of Bias classification: Low.

[2] (Ariagno, Mirmiran et al. 2003). Sample: Sixteen asymptomatic preterm infants. Setting: Home. Outcome variable: Sleep, arousal, heart rate variability. Funding: Not stated.	Longitudinal study of premature infants. Each infant was recorded in both supine and prone positions. Recording length: "Each infant was recorded at their usual nap time, between 11am and 4 pm".	One time-lapse video camera (Panasonic model AC.6730. Osaka. Japan). "The camera framed the infant's face and upper body for interpretation of sleep behavior". Camera operator not stated.	Deductive; Quantitative; Longitudinal; Cross-Over.	Strengths: Each infant acted as own control. Validated coding scheme. Weakness: Recordings of daytime naps possibly of insufficient length to sufficiently capture the phenomenon of interest (sleep cycling). Small sample size. Risk of Bias classification: Moderate.
[3] (Awais, Long et al. 2020). Sample: "seven neonates". Setting: Hospital. Outcome variable: Sleep versus wake Funding: Government and non-profit organization.	Development of an automated algorithm for classifying neonatal sleep versus wake. Uses facial recognition software. 'Convolutional neural networks' (CNN). In computing science this is a form of deep learning whereby a software algorithm analyzes visual imagery. Focused on only two states (sleep and wake).	Not stated. "Video data collection took place in a controlled environment with fixed camera placement and stable lighting conditions under the supervision of nurses and pediatricians" (p5).	Deductive; Quantitative; Evaluation study.	Weaknesses: Risk of starting time bias. No clear recording protocol. Accuracy, sensitivity, and specificity of 65.3%, 69.8%, 61.0%, respectively. Overall performance was described by the authors as "quite modest" and "low" when used to classify neonatal sleep and wake states (p3).

				Small sample size. No camera positioning protocol. Risk of Bias classification: High.
[4] (Axelin, Cilio et al. 2013). Sample: one premature infant. Setting: NICU. Outcome variable: Sleep versus wake. Funding: Not stated.	Longitudinal recording of an infant's daily NICU care. Infant had a diagnosis of hypoxic ischemic encephalopathy (HIE). Study sought to "explore the feasibility of using continuous video-EEG to measure the different aspects of infant daily care (handling by professional or parent caregivers, behavioral state, stress and pain, and administration of analgesia)" including sleep. Recording length: 4 days and 5 hours.	One integrated system: "NicoletOne (MFI Medical Equipment, Inc, San Diego, California) video-EEG system" (p266). Camera positioning: "the infant's whole body is videotaped using an overhead mounted camera" (p265). "the video and the EEG tracing are viewed side by side on a split screen, and it is possible to correlate the brain activity to external stimuli". Operator not stated.	Inductive; Qualitative & quantitative; Longitudinal; Case study; Evaluation study.	Strengths: Trained coders. Both coders were blinded to the hypotheses being tested. Incorporation of inter-rater reliability. Risk of Bias classification: Low.
[5] (Baddock, Galland et al. 2006). Sample: Forty routine bed-sharing infants and 40 routine cot-sleeping infants (aged 5–27 weeks). Setting: Home.	Sought to observe the behaviour of infants sleeping in "the natural physical environment of home", comparing the 2 different sleep practices of bed sharing and cot sleeping quantifying to factors that have been identified as potential risks or benefit. Recording length: 2 consecutive nights. "The first night involved video recording only,	One "small surveillance camera (CEC-C38, Panasonic, Osaka, Japan)" A small, handheld portable television was used as a monitor to ensure correct positioning. An infrared light source (Dennard [Fleet, United Kingdom] 12 volt. 880 Med 50).	Deductive; Quantitative; Triangulation of methodologies (questionnaire and phone interview (1, 3, and 6 months of age); Parental questionnaires; Maternal salivary cotinine "to monitor cotinine, nicotine, and an internal	Strengths: Featured an adaption night. "The reason we videoed 2 nights was to establish whether there was any difference in behavior because of "first-night effect" or the presence of the sensors on the infant. Using Bland-Altman plots we found no

Outcome variable: Awakenings for breastfeeding. Funding: Government.	and the second involved video and physiologic recording". A custom-developed computer software was used for coding in lieu of modern Observer style software.	An analog video recorder (Panasonic AG-TL700) set to "long play" that allowed 15 hours of recording on a 3-hour videotape. Camera "mounted on a stand above the bed so that the full width and the top third of the bed were in the field of view to allow recordings of the infant's movements and positioning and any infant/parent interactions." An infrared light source was "mounted on the stand to reflect light off the ceiling on to the recording area." Person operating camera not stated.	standard"); Cross-sectional.	significant difference on key behavioral indices". Each group was "comparable with regard to gestational age, birth weight, male:female ratio, age at study, and weight at study". Power: "Two samples of 40, using the 5% level of significance, have 80% power to show this difference between groups". Risk of Bias classification: Low.
[6] (Baddock, Tipene-Leach et al. 2017). Sample: 200 Maori infants. Mean infant age was 50 days (SD 19.1) (bassinet group) and 47 days (15.7) (wahakura group). Setting: Home. Outcome variable: SIDS risk factors. Funding: Government; Academic institution.	Use of an indigenous sleep basket (wahakura) versus a bassinet as they pertain to SIDS risk factors: infant sleep position, head covering, breastfeeding, bed-sharing, and maternal sleep and fatigue. RCT: Mothers "were randomized to receive a bassinet or wahakura and asked to sleep the infant in this device from birth. Questionnaires at 1, 3, and 6 months and an overnight infrared video in the home at 1 month were completed".	Not stated how many "camera(s)". Each was infrared. Camera positioning: "in the bedroom" Operator not stated.	Deductive; Quantitative; Longitudinal; Randomised Controlled Trial.	Strengths: Validated coding scheme. Incorporation of inter-rater reliability. 5% level of significance and 80% power. Weakness: Poor recruitment rate (35.4%). Possible undesirability bias. Risk of starting time bias. No clear

	Recording length: Around 10 hours (one night) per infant.			recording protocol. Risk of attrition bias. Missing data/Risk of information bias: "Successful video recordings at the 1-month sleep study occurred for 80 (83%) of 96 of the bassinet group and 79 (78%) of 101 of the wahakura group". Thus, the sample size of infant videos was 159/200. Risk of Bias classification: Moderate.
[7] (Baddock, Galland et al. 2012). Sample: "Forty healthy, term infants, aged 0 to 6 months who regularly bed-shared and 40 age matched Cot Sleeping infants". Setting: Home. Outcome variable: Desaturation events and rebreathing episodes. Funding: Not stated.	Study looking at family behaviour, environmental factors, and infant physiology (bedsharing versus cot sleeping). Unlike other sleep studies that utilize multiple forms of data capture, this study did not do so for cross-validation purposes. Rather, video was used to ascertain "infant's sleep position, movements, and parent–infant interactions" whilst physiological methods were used for sleep staging and apnea detection. Recording length: 2 consecutive nights.	"A small surveillance camera (Panasonic CEC-C38, Osaka, Japan) and infrared light source allowed recordings on a video recorder (Panasonic AG TL700, Osaka, Japan), set to "long play" (to enable 15 hours of recording on a 3-hour videotape)." Camera "mounted on a stand above the bed so that the full width and the top third of the bed were in the field of view to allow recordings of the infant's movements and positioning and any infant/parent interactions". An infrared light source was "mounted on the stand to reflect light off	Deductive; Quantitative; Triangulation of methodologies (Polysomnography); Cohort Study	Strengths: Infants in each group were matched for age and season of study. Adaption night. Risk of Bias classification: Low.

		the ceiling on to the recording area". The level of CO_2 in the microenvironment around the infant's face was measured from air sampled through a catheter attached to midway between the inner canthus of the infant's eye and the lateral edge of the nostrils. "Infants were set up and recordings started by the researchers. Families were then left unattended for the night. Recordings were turned off in the morning when the researchers returned".		
[8] (Batra, Teti et al. 2016). Subjects: "Healthy, term newborns". 160 one-month-olds (which dropped to) 151 three-month-olds (which dropped to) 147 six month olds. Setting: Home. Outcome variable: Environmental SIDS risk factors during sleep. Funding: Not stated.	Sought to "determine the frequency of environmental risk factors [for infant death] by using nocturnal sleep videos of infants". Recording length: "For 1 night at ages 1, 3, and 6 months".	1 - 4 cameras per family depending on parental reports of bedtime or sleep locations. "Bosch Divar XF 8 channel digital video recorder (Bosch, Fairpoint, NY), Infrared Color Couple Charged Device (ML) Cameras (Spectral Instruments Inc, Tuscan, AZ), Channel Vision 5014 Microphones (Channel Vision Technology, Costa Mesa, CA), and an Audiovox D9000 Portable DVD/ CD Player (Voxx Electronics Corp, Hauppauge, NY). All cameras were wired directly to the digital video recorder by using Mini coaxial cable television cables with an option of a wireless setup by using a Video Transmitter Kit from Videocomm Technologies	Inductive; Qualitative and quantitative; Longitudinal.	Strengths: Incorporated inter-rater reliability. "Regarding attrition, there were no demographic differences between those who did and did not complete the 6-month observation period" (p3). Weakness: Risk of attrition bias. No clear coding protocol: Risk of observer bias.

		(Burlington, ON, Canada)." "At infant ages 1, 3, and 6 months," research staff visited each family to set up video equipment in the area(s) of the home where the infant commonly slept". "For all families, 1 camera and microphone setup were suspended on a boom stand above the infant's primary sleep location to provide a clear view of the infant's head, body, and primary sleep surface. Other cameras were set up to provide alternate views or in alternative sleep locations. Infrared illuminators were set up to provide bounce lighting to illuminate the infants' room if needed". "At each study time point, video recordings were initiated by parents 1 hour before the start of bedtime. Recordings continued throughout the night until the infant was fully awake in the morning".		Risk of Bias classification: Moderate.
[9] (Burnham, Goodlin-Jones et al. 2002). Duplicated in (Goodlin-Jones, Eiben et al. 1997). Sample: "Approximately 20 infants (10 males) were recruited into each of 4 age groups:	Longitudinal study assessing whether introducing a sleep aid infused with maternal scent at different ages would impact infants' self-soothing. "Each infant was studied on 3 occasions: their starting age of 3, 6, 9, or 12 months (Time 1), then 2 weeks later (Time 2), and finally, 3	One camera (RCA Model TC2011), equipped with a wide angle lens, an auto-iris, and an Ultricon video tube sensitive to low levels of illumination. A 20 foot cable connected the camera to a Panasonic variable speed time-lapse VTR recorder, Model NV-8030	Deductive; Quantitative; Triangulation of methodologies (Parental questionnaire); Longitudinal.	Strengths: Validated coding scheme. Incorporated inter-rater reliability. Weaknesses: Risk of confounding. "Documentation of crib location was not available

3, 6, 9, and 12 months. A total of 86 families were recruited". Setting: Home. Outcome variable: Use of sleep aids (soft object; pacifier; thumb/finger/hand; odor-laden T-shirt). Funding: Research organisation.	months from Time 2 (Time 3). Each occasion included 2 nights of videotaping the infant's sleep in his/her natural environment. Thus, each infant had 6 nights of video-recorded sleep for analysis".	An infrared light source in a spectral range compatible with the video tube's sensitivity provided sufficient illumination for normal sleeping conditions to be maintained. A QSI Model 600 time-date generator superimposed continuous clock time and date on the video tape. A microphone, placed near the bed, recorded fussing and crying vocalization. "The camera was mounted on a tripod as close to the infant's bed as possible. A 20 foot cable connected the camera to a Panasonic variable speed time-lapse VTR recorder, Model NV 8030, placed some distance from the bed or in an adjacent room". Operator not stated.		for every infant; thus, the analysis is derived from a subset of infants (N = 77)". Risk of Bias classification: Moderate.
[10] (Cabon, Porée et al. 2019). Sample: Ten premature newborns. Setting: NICU. Outcome variable: Quiet Sleep (QS), Active Sleep (AS), Drowsiness (D), Quiet Alert (QA) and Active Alert (AA). Funding: Government.	An attempt at semi-automatic sleep stage classification using a facial reference point for tracking. The proposed method was successful at estimating alert stages (QA and AA) but poor at differentiating between the three calm stages (Quiet Sleep, Active Sleep and Drowsy). Longitudinal study: "between the 7th and the 11th day of life". Recording length: "between 10 and 32 min, leading to a total	Camera resolution of 720×756 pixels and recorded 25 frames per second. A camera "was installed near the bed in order to observe the major part of the body". "To consider conditions compatible with a monitoring context, no specific setup was imposed" (p363). Operator not stated. Integrated microphone: "Sound was acquired by a microphone integrated in the camera with a frequency sampling of 8 kHz. The choice of this low	Deductive; Quantitative; Longitudinal; Evaluation Study.	Weaknesses: No camera positioning protocol: "To consider conditions compatible with a monitoring context, no specific setup was imposed" (p363). Risk of researcher bias due to subjective coding: "intermediate states being difficult to objectively determine, the user decided if the eyes were 'Open' or 'Closed'" (p367).

	duration of more than 4h (242 min and 14 s)"	sampling rate has been motivated by our objective to simply detect periods with sound activity while keeping a fast computation time".		Small sample size. Risk of starting time bias. No clear recording protocol. Risk of Bias classification: Moderate.
[11] (Camerota, Tully et al. 2018). Sample: 90 African American 3-month olds. Setting: Home. Outcome variable: Sleep duration and fragmentation. Funding: Government.	Methodological comparison of video, actigraph and parent report. Infant sleep data. High level of agreement for variables indicative of sleep schedule; moderate agreement for indices of sleep duration and fragmentation. Recording length: one night.	"Four infrared, high-definition, color Hikvision (DS-2CD2432F-IW) cameras with internal microphones". Camera position: "Research Assistants probed caregivers about the infant's sleep locations, as well as any other areas of the home where the infant and caregiver might spend time together before bedtime or during the night. These locations guided the choice of camera placement". "Cameras were connected to an Exacq (IPS04-1000-LC) video surveillance recorder via Power over Ethernet (Wren, Launer et al. 2021) ports of a NETGEAR ProSafe Plus (GS108PE) switch. Ethernet cables were secured to the floor and furniture for safety. Caregivers were instructed to turn on the video equipment at 6:30 pm". Operator not stated.	Deductive; Quantitative; Triangulation of methodologies (Actigraphy and sleep diaries); Evaluation study.	Strengths: Incorporated inter-rater reliability. Weakness: Risk of first night effect. "For consistency of comparison, only the first night of data were compared for all methods" (p5). Risk of attrition bias/unacceptability bias. "Of the 103 families recruited into the study, 12 did not complete the 3-month home visit. Of the 91 families who completed 3-month home visits, 82 had videosomnography data, 82 had actigraphy data, and 87 had sleep diary data" (p5). Risk of attrition bias/ Risk of information bias. "Of the 82 families with videosomnography data, 2 infants

				were asleep when the recording began and 11 infants were still asleep when the recording ended. Because accurate sleep measures could not be determined in these cases, there are 2 cases of missing sleep onset time data, 11 cases of missing rise time data, and 13 cases of missing sleep period, night wakings, sleep time, wake time, and longest sleep period data" (p5). Risk of Bias classification: Moderate.
[12] (Cattani, Alinovi et al. 2017). Sample: "10 single camera-based video recordings of newborns". Setting: NICU. Outcome variable: Neonatal clonic seizures and apneas. Funding: Not stated.	Motion analysis by video processing. Proposal of "a monitoring system based on the detection of pathological movements, characterized by the presence or absence of a significant periodic component (i.e. rhythmic movements)". Comparison between the proposed system and EEG. Recording length: 1 hour.	Three cameras. "A multi-sensor system is less affected by the patient's position, because all main viewing angles are monitored by different sensors". Each video has these settings: * sampling rate: 25 frames/s (T= 40ms); * resolution: 360×288 pixels; * length: 5 min. "The system is composed of three cameras: the first two cameras are arranged orthogonally in order to frame the baby by the front and the side, the third one is attached to	Deductive; Quantitative; Evaluation Study.	Strength: Even when blankets were covering the newborn, the proposed system was sensitive enough to detect the small movement of the chest, indicating that the "enhancement method may indeed enable a correct detection of the diseases". Weakness: Technical effect. "Some residual noise" described as: The video and intergrated depth sensor "are afflicted by a significant and systematic issue: the shadowing

		the cradle to frame the face of the newborn". Operator not stated.		noise. This problem, common to all structured-light approaches which use an offset camera to determine a depth map, consists of the presence of regions where the projected pattern is shadowed by foreground objects, making it impossible to estimate the corresponding depth. Because of this issue, it becomes difficult to apply a simple difference between consecutive depth frames: in fact, in the processed image, besides movement parts, background areas could not be correctly detected" (p160-161). Background-foreground segmentation is used to mitigate the problem "to filter out all unnecessary pixels". "For performance analysis, we discarded 6 of these available 23 apneas, because: in 4 of them the cameras were covered by medical personnel" (p163).

				Risk of starting time bias. No clear recording protocol. Small sample size. Risk of Bias classification: Moderate.
[13] (Cremer, Jost et al. 2016). Sample: 38 infants born <32 weeks gestational age and/or <1500 g birth weight. Setting: NICU. Outcome variable: awake; active sleep; quiet sleep. Funding: Not stated.	Development of circadian rhythm in premature infants. Videos with and without phototherapy were compared for amounts of quiet sleep and active states (awake + active sleep). Recording length: 3 hours [mean of 185 min (SD: 11 min)] over the first 5 days of life.	Two cameras. Video recordings "were taken through the incubators' roofs and/or doors. Initially, the camera was filming from above for examination of body movements and respiration. After a pilot phase, subjects were filmed with an additional camera focusing on the face of the infant for better examination of the eyes". "In sunny conditions, a curtain was installed to shield the incubator from direct sunlight, in order to reduce reflections and limit alterations of light conditions". 55 of the 215 videos were not included due to corruption during file compression. Operator not stated.	Deductive; Quantitative; Cohort Study.	Strengths: "relatively large number of data points resulting from a large amount of video material". Validated coding scheme. Trained coders and inter-rater reliability. "Three medical students in their 9th semester analysed the videos. A paediatric sleep specialist trained and supervised the students using a standardized analysis and assessment protocol. Unclear situations were resolved by discussion with the paediatric sleep specialist." (p519). Weaknesses: Authors acknowledge "this study did not account for Indeterminate Sleep, an obvious

				phenomena when only scored through video observation" (p522). Technical effect: "there was an inconsistency in video quality due to the subjects' movements or routine nursing measures". Confounding risk factors: Infants may have received different treatments. "This is an observational study. Subjects neither received nor were withheld any special care... Phototherapy for treatment of hyperbilirubinemia was prescribed dependent on fixed thresholds based on the infants' GA and postnatal age". Infants differed in characteristics. "The current population was diverse in terms of GA, birth weight and co-morbidities". Infants did not act as their own control. High attrition rate. "160 of the planned 215

				videos were analysed, thereof 38 with and 122 without phototherapy; 55 videos were not included due to corruption during file compression (35), withdrawal of consent (National Childbirth Trust 2015) and secondary exclusion due to pronounced growth retardation in one mature subject (5)". Performing multiple testing – subgroup analysis ("fishing for P"). Risk of Bias classification: High.
[14] (Di Capua, Fusco et al. 1993). Sample: 12 newborns with the disorder Benign Neonatal Sleep Myoclonus (BNSM) Setting: Hospital. Outcome variable: Benign neonatal sleep myoclonus (BNSM) (repetitive myoclonic jerks of the extremities exclusively during non-rapid eye movement sleep).	Looking for clinical markers of the sleep disorder - benign neonatal sleep myoclonus (BNSM) (repetitive myoclonic jerks of the extremities exclusively during non-rapid eye movement sleep). The clinicians sought to distinguish between convulsive disorders (which are pathological and require treatment) and benign myoclonus of early infancy (which is rare but considered clinically normal). Differing clinical status, EEG expression, and different relation to the sleep wake cycle enable	Not stated.	Inductive; Longitudinal; Cohort Study; Quantitative and Qualitative.	Weaknesses: Risk of reporting bias – numerical data presented only. Risk of starting time bias. No clear recording protocol. No camera positioning protocol. Small sample size. Risk of Bias classification:

Funding: Not stated.	the two diagnosis to be distinguished. Videopolygraphic monitoring recordings were obtained during wakefulness and active and quiet sleep. The 12 infants were observed for periods ranging from 12 to 60 months (average 33).			Unclear (not enough details).
[15] (Gerard, Harris et al. 2002). Sample: Twenty-six healthy infants, mean age 80 + 7 days. Setting: Laboratory. Outcome variable: Arousals. Funding: Government.	Sought to examine "the effect of swaddling on spontaneous arousals during sleep". Recording length: "during naps".	2 cameras (JVC Professional Products, Elmwood Park, NJ) "Two separate cameras simultaneously recorded the infant and the respiratory channels of the polygraph" (p1). Camera positioning not stated. Operator not stated.	Deductive; Quantitative; Triangulation of methodologies (Polysomnography); Cross-sectional.	Strength: Blinded coder. Incorporation of inter-rater reliability. "97% agreement when 1 reviewer used behavior and respiratory criteria alone and the other reviewer, blinded to the infant's behavior, used EEG/EOG criteria alone". Weaknesses: Risk of starting time bias. No clear recording protocol. No camera positioning protocol. Risk of Bias classification: Unclear (not enough details).
[16] (Giganti, Ficca et al. 2006).	Sleep scoring (inc AS & QS) premature infants	One "S-VHS video-camera" and a "video-	Inductive; Qualitative &	Strength: Adaption period (30mins)

Sample: Twelve low-risk premature infants (seven males, five females). Setting: NICU. Outcome variable: Infant behaviour and infant-care interventions (medications, feedings, etc.) carried out in a NICU. Funding: Government; Academic institution.	in a NICU using traditional VHS. Sought to "evaluate, through the analysis of body motility patterns, the day—night distribution of number and duration of awakenings between preterm and near term time" (p436). "Infant behaviour and all the interventions (medications, feedings, etc.) carried out by the neonatal ward staff were video-recorded" (p436). Recording length: "about 24 h (mean 22.01, range: 19.08—24.01).. The 24-h period was divided in two subperiods: daytime (0800—2000 h) and nighttime (2000—0800 h)".	recorder (Panasonic SG-DP200)". "All infants were continuously observed and video recorded in the incubator, which was located in a quiet room of the neonatal ward; older infants, already in a cot, were put into the incubator at neutral temperature for the recording". Camera was "set approximately 1 m above the incubator, at an angle of 458". "No coding was given in case of technical problems (nurses standing in front of the camera, delay in the introduction of a new cassette in the recorder, etc.)". Operator not stated.	quantitative; Cross-sectional.	Weakness: Small sample size. Risk of Bias classification: Low.
[17] (Goodlin-Jones, Burnham et al. 2001). Sample: 80 infants in one of four age groups (3, 6, 9, or 12 mo). Setting: Home. Outcome variable: Vocalized awakenings. Funding: Not stated.	Sought to "describe the development of self-regulating behaviors in response to middle of the night awakenings in infants at four ages during the first year of life". "two consecutive nights of sleep were recorded on each of two occasions, Time 1 (T1) and Time 2 (T2), separated by 2 weeks". Recording length: four nights in total.	Portable time-lapse video system consisting of one time-lapse videocassette recorder (AG-6740P; Panasonic, Cupertino, CA), one low-level illumination camera (e.g., VDC-9212; Sanyo, San Diego, CA), one 12-inch video monitor, and one microphone to record sound. Positioned "on a tripod next to the child's crib". "Video and audio signals were recorded by using the 18-hour time-lapse	Deductive; Quantitative; Triangulation of methodologies (Parent Questionnaires) ; Longitudinal.	Strengths: "Research assistants were trained to 85% reliability" for coding. Validated coding scheme. Incorporated inter-rater reliability. Weaknesses: Small sample size. "Even though the overall sample

	Parent Questionnaires used "to assess psychological well-being" rather than validate the video.	mode so that a full 18 hours could be recorded on one 2-hour standard VHS videotape. A time code generator recorded real clock time on the tape". "Vocalized awakenings" formed a key category of interest however coding of this behaviour relied on the quality of the audio: "An awakening was coded as "vocalized" if the infant cried, cooed, or babbled and was audible on the videotape recording" (p6). Technical effect: Eighty-eight infants were initially enrolled in the study. "For six infants, the equipment failed or data were insufficient". Operator not stated.		consisted of 80 infants, once the age groups were separated for data analyses there may have been too small of a sample at each age for detection of differences on some variables". Comparison group comprises of other infants living in different homes. Risk of starting time bias. No clear recording protocol. Risk of Bias classification: Moderate.
[18] (Henderson, France et al. 2010). Sample: 31 "typically developing infants". Setting: Home. Outcome variable: Sleep consolidation. Funding: Academic institution; lottery grant.	Consolidation of infants' self-regulated nocturnal sleep over the first year examined by sleep diaries. Accuracy of these parent reports were assessed by using videosomnography. Study found high accuracy in contrast to previous studies. ENVIRONMENT: Crucially, only 41% of the 75 participants agreed to video recording in their home (n=31). Recording length: 2 consecutive nights.	One time-lapse video recorder. Positioning not stated. Operator not stated.	Deductive; Quantitative; Triangulation of methodologies (Parental sleep diaries); Longitudinal.	Strength: Trained coders. Weaknesses: no coding protocol or taxonomy for video data. Risk of observer bias. Basic data inadequately described (no video data presented). Risk of starting time bias. No clear recording protocol.

				No camera positioning protocol. Risk of Bias classification: Unclear (not enough details).
[19] (Kahn, Barnett et al. 2021). Sample: 1074 infants aged 2 weeks to 18 months (M = 8.6 months, SD = 4.8). Setting: Home. Outcome variable: Sleep–wake patterns. Funding: Commercial.	Sleep of infants was objectively assessed using computer-vision technology. Sleep and infant exposure to screens was additionally reported by parents in an online survey. Movement-based "state-of-the-art auto-videosomnography technology" via commercial app. Features automated coding. Recording length: > 3 nights.	One "Nanit baby monitor" "These small monitor devices are mounted above the infant's crib, continuously recording motion at a pre-defined nighttime period, allowing assessment of nighttime—but not daytime—sleep". "In addition to producing objective outputs, camera-based devices incorporating computer-vision algorithms have the potential to yield nightly metrics throughout prolonged periods of time". Mounted above the infant's crib. Operator: parents.	Deductive; Quantitative; Triangulation of methodologies (Parental online survey); Cross-sectional.	Strength: validated coding scheme. Weaknesses: Risk of researcher bias/ Industry Sponsorship bias and Spin bias. Possible (funding-related) conflict of interest. "Conflict of interest statement. M.K. and N.B. have served as consultants for Nanit. A.G. was an employee of Nanit at the time of study implementation. M.G. has served a Pro-Bono consultant for Nanit". Risk of insensitive measure bias. Poor validity of methods. Relies on movement thus weak at ascertaining non-movement based sleep behaviours. Risk of starting time bias. No clear recording protocol.

				Risk of Bias classification: High.
[20] (Lehtonen, Johnson et al. 2002). Sample: 13 ventilated extremely-low-birth-weight infants. Setting: NICU. Outcome variable: Oxygen desaturations. Funding: Not stated.	Studies the association between hypoxemic episodes (low level of oxygen in the blood) and state (active sleep, quiet sleep). "Eye movements were scored from a high-quality video image because electrographic detection of eye movements is unreliable at this early gestational age". Recording length not stated.	Two cameras. Nicolet-Bravo equipment (Nicolet Biomedical, Madison, Wis): A low-light black-and white camera (Dage-MTI, Michigan City, Ind) was used for the facial image and a color camera (Sony Digital 8, New York, NY) for the full body image. Cameras positioned "at the bedside". Operator not stated.	Deductive; Quantitative; Triangulation of methodologies (Polysomnography); Cross-sectional.	Strengths: "Scoring was done in 5 separate passes by using double speed of the video. The scorer was blinded to the episodes of hypoxemia". Incorporated inter-rater reliability. Validated coding scheme. Weaknesses: Small sample size. Risk of confounding. "As we specifically aimed to study extremely immature ventilated infants exhibiting episodes of hypoxemia, our subjects were receiving various medications and had medical complications of prematurity that might have altered their physio logic states" (p367). Risk of starting time bias. No clear recording protocol.

				Risk of information bias. Missing data. An average of 8 minutes were "unscorable" per 3 hour recording. Risk of Bias classification: Moderate.
[21] (Lijowska, Reed et al. 1997). Sample: 19 healthy infants (2–26 wk old). Setting: Not stated. Outcome variable: Arousal. Funding: Government.	Asphyxia study testing "two different rebreathing environments and also during exposure to a hypercarbic hyperoxic gas mixture". "We previously observed that infants sleeping face down frequently gain access to fresh air by suddenly lifting and turning their heads to the side, without any other evidence of arousal. The present study was designed to further investigate this and other airway protective behavior during sleep". 19 infants were videotaped: 15 while face covered, 3 while face down, 8 while breathing CO2. Recording length not stated.	One infrared camera (JVC Professional Products, Elmwood Park, NJ). "The infant was filmed with an infrared camera, and, simultaneously, the polygraph signal was filmed and displayed on a split-screen video monitor". "Respiratory sounds were recorded by using a small microphone taped directly to the lateral submandibular part of the infant's neck". Operator not stated.	Inductive; Quantitative & Qualitative; Triangulation of methodologies (Polysomnography); Cross-sectional.	Strength: validated coding scheme. Weakness: setting not stated. No camera positioning protocol. Risk of Bias classification: Unclear (not enough details).
[22] (Long, Otte et al. 2019). Sample: "10 healthy term infants aged 5	Used a motion detection algorithm to automatically code sleep vs wake. They compared this with polysomnography (PSG) - based human scoring. The PSG was able to	One infrared camera. "The IR video recording (at 376 480 pixels) and its corresponding raw RS motion estimates had a frame rate of 10 Hz".	Deductive; Quantitative; Evaluation study.	Strengths: Trained coder. Validated coding scheme.

months on average (range 3–9 months)". Setting: Laboratory. Outcome variable: Sleep versus wake. Funding: Not stated.	code more nuanced behavioural states (e.g., AS, QS) whereas the motion detection algorithm was only able to code binary sleep vs wake. Recording length: "For each infant video, data with an average duration of 1.16 0.43 (mean / standard deviation) hours was included, resulting in a total of 11.6 h used for the analyses".	Camera positioning: "IR camera placed in a "look-down" view above an infant bed... The whole mattress of the bed was visible". Fixed camera placement. Operator not stated.		Weaknesses: Risk of starting time bias. No clear recording protocol. Risk of Industry Sponsorship bias; Potential conflict of interest. "At the time of writing, X.L., R.O. and E.v.d.S. are employed by Royal Philips, Research". Risk of Bias classification: High.
[23] (Long, Espina et al. 2021). Sample: "Five preterm infants". Setting: NICU. Outcome variable: Sleep versus wake. Funding: Not stated.	Observational pilot study of automated coding. "Contact-free video-based actigraphy quantifies body movement during long-term sleep assessments and does not require a sensor". Study "evaluated its feasibility and performance in identifying sleep-wake states in preterm infants". "A spatiotemporal recursive search algorithm detected motion, unaffected by illumination changes, from the video frames". "Both methods [traditional actigraphy and video-based	"A uEye Monochrome video camera (IDS GmbH), placed inside the infant's incubator produced 736 × 480 pixel images eight times a second". "The motion detection also picks up other activity outside the incubator, such as nursing staff, and this can result in sleep being misclassified as wakefulness". "We used a monochrome camera that required sufficient illumination". Operator not stated.	Deductive; Quantitative; Triangulation of methodologies (Actigraphy); Evaluation study.	Strengths: Validated coding scheme and trained coder. Weaknesses: Limited data from only five infants, with a few hours per infant. Risk of Industry Sponsorship bias; Potential conflict of interest. "At the time of writing, XL, JE, RAO and WW were employed by Royal Philips, a commercial health technology company". Risk of starting time bias. No clear

	actigraphy] failed to identify being asleep with increased activity or being awake with reduced activity". Recording length: Mean was 5.6 ± 0.7 h per infant.			recording protocol. Risk of Bias classification: High.
[24] (McIntosh, Tonkin et al. 2013). Sample: Seventy-eight healthy infants (39 in each group) born between 37 and 42 weeks' gestation with no known current medical complications studied between the fourth and eleventh day of life. Mean age: 8 days. Setting: Home. Outcome variable: Apneas. Funding: Charity; Research Foundation.	Sought to "test the hypothesis that a foam plastic insert that allows the infant head to rest in a neutral position in sleep may prevent obstruction of the upper airway and thus reduce episodes of reduced oxygenation in term infants in car seats". Only the first hour of sleep was analysed. Recording length: 1 hour.	Camera details not stated.	Deductive; Quantitative; Triangulation of methodologies (Polysomnography); Randomized controlled trial (parallel-group design).	Strengths: "Randomization codes were pre-generated and supplied in numbered, sealed envelopes that were opened on the day of the study". Validated coding scheme. Incorporated inter-rater reliability. Statistical power: "80 infants was required to have an 80% chance of detecting a two-thirds reduction with the insert". Weaknesses: Risk of attrition bias. "Two infants in the no-insert group never slept and were excluded from additional analysis". Risk of starting time bias. No clear recording protocol.

				No camera positioning protocol. Basic data not adequately described. Video is used but data not presented. Risk of Bias classification: Moderate.
[25] (McKenna, Mosko et al. 1997). Sample: 20 routinely bedsharing and 15 routinely solitary sleeping Latino mother-infant pairs when infants were 3 to 4 months old. Setting: Laboratory. Outcome variable: Awakenings for breastfeeding. Funding: Not stated.	Laboratory study of the effect of mother-infant bedsharing on breastfeeding behaviour. Recording length: "All night" (3 nights). Routinely bedsharing infants breastfed approximately three times longer during the night than infants who routinely slept separately.	Not stated. Only details given are: Infrared audiovisual.	Deductive; Quantitative; Cross-sectional; Cross-over; Triangulation of methodologies (Polysomnography; home sleep logs).	Strengths: Each dyad acted as their own control. For each pair, an adaption night was followed by one night each of bedsharing and solitary sleeping. "Randomly assigned order" (p215). "Mothers were blind to all experimental hypotheses and instructed only to prepare and respond to their infants as they would at home. Mothers also retired at their usual times, and monitoring was terminated after mother and infant had awakened the next morning at their usual times" (p215). Weaknesses: "A large digital clock placed in the camera field

				allowed calculation of breastfeeding data to the nearest minute" (p215). Because the reviewers relied upon a digital clock for time data, they could not code data < 1 minute as this was below the resolution of the digital clock. Small sample size. Risk of starting time bias. No clear recording protocol. No camera positioning protocol. Risk of Bias classification: Unclear (not enough details).
[26] (Miano, PiaVilla et al. 2009). Sample: "Twenty-three healthy newborns and infants". Setting: Hospital. Outcome variable: Non-rapid eye movement (NREM) sleep instability, as measured by the cyclic alternating	Triangulation between methodologies to score infant sleep and apneas. Recording length: 3-hours (120 minutes coded).	Not stated.	Inductive; Quantitative; Triangulation of methodologies (Polysomnography); Cross-sectional.	Strength: Validated coding scheme. Weaknesses: Basic data not adequately described. Video is used but data not presented. Insensitive measure bias. Poor validity of methods: The study did not meet its aim due to reliance upon

pattern (Di Capua, Fusco et al. 1993). Funding: Not stated.				EEG which is inappropriate for this sample. The study incorporated video recordings into the triangulation of methodologies but failed to detail video's role. The authors' conclusion (that analysis of AS/QS instability is inappropriate in infants <3 months) was thus biased due to poor validity of methods. Further, the authors recognise the potential insufficiency of coding only 2 wakefulness-sleep cycles (120 minutes) versus all-night recording. Small sample size. No camera positioning protocol. Risk of Bias classification: High.
[27] (Patel, Paluszynska et al. 2003). Sample: 56 healthy 1- to 6-month-old infants.	Study investigating rebreathing in prone sleeping infants. The authors sought to determine the frequency of failure to arouse and escape from the face-down position	Video was primarily used as a means to synchronise physiological output with behavioural observation for later coding: "The infant and polygraph tracing were recorded with an infrared video camera (Videonics, Campbell, CA) so as to	Inductive; Quantitative; Triangulation of methodologies (Polysomnograp hy); Cross-sectional.	Weaknesses: Risk of confounding. Researchers physically manipulated most of the subjects to obtain data of interest when that data was not naturally

Setting: Laboratory. Outcome variable: Oxygen desaturations. Funding: Government.	during periods of "rapid desaturation".	allow correlation between infant behaviors and physiologic recordings on analysis at a later date". One "infrared video camera (Videonics, Campbell, CA)". Operator not stated.		forthcoming: "Approximately 10% of infants turned face down spontaneously. If not, then he or she was turned prone and the head was positioned face down". Convoluted way to avoid having to code video data: Rather than coding the video data, the authors used a pulse oximeter to record infant movement. When this failed, they relied upon ECG movement artifacts: "In 6 of the 25 desaturation episodes that were studied, the pulse signal was not recorded in which case we relied on presence or absence of movement artifacts in the ECG because movement artifacts in the ECG were invariably present when the pulse trace reflected infant movements". The authors' reliance upon paper polygraph tracings led them to develop a novel random sampling procedure for analysis: "Each page of the

				tracings represented 30-second epochs of the study. We used a random number generator to select a page (www.randomizer.org). If the selected page met control criteria, then we selected that page. If not, then another number was drawn until a nonrebreathing page without desaturation was selected. The beginning of the page was used as the control period. This entire method was repeated for each desaturation for each infant using this method". No camera positioning protocol. Risk of Bias classification: High.
[28] (Paul, Hayes et al. 2020). Sample: 194 infants < 6 months of age. Setting: NICU and laboratory. Outcome variable: Sleep consolidation.	Sought to "investigate factors affecting total sleep time (TST) during infant polysomnography (PSG) and assess if <4 hours of TST is sufficient for accurate interpretation". One hundred thirty-four of 242 (55%) studies were done during the day between 8 a.m. to 4 p.m.	Camera details not stated.	Deductive; Quantitative; Triangulation of methodologies (Polysomnography); Evaluation study.	Strength: Validated coding scheme. Weakness: No camera details. Risk of starting time bias. No clear recording protocol. Risk of detection bias: nasal

Funding: Not stated.	Recording length: 8 hours.			pressure transducers were utilized but limited due to some infants requiring supplemental oxygen, pulse oximeter. "The presence of nasal tubes including impedance probes seemed to affect TST". Risk of informed presence bias: "Factors that affected Total Sleep Time such as Post Menstural Age, medical complexity, location of the study, and timing of the study were too closely intertwined by our clinical bias to meaningfully disentangle". Risk of confounding: Different environments used for different participants. "Studies performed in the sleep laboratory yielded much higher TST than those done elsewhere". Risk of information bias: Missing data. Most recordings had 8 hours of total recording time, "unless

				limited by technical issues". Risk of Bias classification: High.
[29] (Schwichtenberg, Choe et al. 2018). Sample: 30 videos of infant/toddler sleep (8 to 30 months of age). Setting: Home. Outcome variable: Sleep versus wake. Funding: Government; non-profit private foundation.	Exploration of automated scoring of sleep/wake states using movement data. Sought to "demonstrate how a signal/video-processing system can be used to generate estimates for sleep vs. wake states, in addition to estimates of sleep timing (sleep onset and morning rise time) and nighttime sleep duration". Infant movements were assessed using "a background subtraction method". Recording length: 1 night.	One "portable, night vision camera (Swann SW344-DWD, Model ADW-400)" Camera "placed over the infant/toddler's primary sleep location" "The first home visit included setting up the VSG recording equipment and providing parents with an actigraph and a parent-report sleep diary". "Parents were instructed to turn the camera on when they started their infant/toddler's bedtime routine and to turn it off in the morning after the infant/toddler was removed from bed".	Deductive; Quantitative; Triangulation of methodologies (actigraphy & parent-report sleep diaries); Evaluation Study.	Strengths and weaknesses: "high sensitivity for sleep but only about half of the wake minutes were correctly identified". "strongest agreement for sleep onset and offset". "However, nighttime waking agreements were poor across both behavioral videosomnography and actigraphy comparisons". Strengths: Incorporated inter-rater reliability. Statistical power: "sufficient power to detect moderate effect sizes. (d=0.50) with two-method differences and kappa agreement (power <0.95)". Risk of Bias classification: Moderate.
[30] (Sharma, Bhattacharyya et al. 2015).	Aim was to present "a non invasive automated sleep apnoea detection	"Quality of the recorded video should be good enough to visually identify	Deductive; Quantitative;	Strength: Incorporated

Sample: "sixteen neonatal infants". Setting: NICU. Outcome variable: Detecting sleep apnoea by identifying absence of respiratory motion. Funding: Not stated.	method, specifically targeted for newborns". Use of an automated algorithm to detect absence of respiratory (Pearlman 1979) motion. Also tested "a respiration simulator which can generate respiration rate with different frequencies".	the subtle respiratory motion of infants." "A video camera is fixed to continually capture the infant in close shot view" "The proposed system is incorporated in an embedded platform with camera interface". "Our developed standalone embedded platform incorporating video camera, and proposed respiration simulator, has following components: 1) USB ports to interface recorder camera. 2) VGA port for display. 3) GPIO pins to generate warning signals. 4) Software to compile and execute coding scripts". Operator not stated.	Evaluation study.	inter-rater reliability. Weaknesses: Technical effect. When amplification is set too high, this can increase noise and other artifacts. An optimum threshold of amplification has not been ascertained and presents an avenue for future research. Risk of starting time bias. No clear recording protocol. Small sample size. Risk of Bias classification: Moderate.
[31] (St James-Roberts, Roberts et al. 2017). Sample: 101 infants assessed at 5 weeks and 3 months of age. Setting: Home. Outcome variable: Sleep consolidation. Funding: Not stated.	Longitudinal study of self-setting behaviours at 3 weeks and 5 months. Comparison between video and parental-report. "Two aims: 1. To assess whether infant development in the first 3 months involves increasing the length of sleep periods or acquiring the ability to resettle back to sleep autonomously after waking in the night.	One self-focusing digital infrared video camera (Sony HDR XR200VE). Camera positioning: "on a tripod directed at the infant's usual nighttime sleep location". "Parents were instructed in using the camera and asked to switch it on when they began settling their infant to sleep at night and off the next morning. They were asked to follow their usual nighttime habits and could switch	Deductive; Quantitative; Triangulation of methodologies (Parental questionnaire); Longitudinal.	Strengths: Validated coding scheme. Trained and blinded coders. Incorporated inter-rater reliability. Risk of Bias classification: Low.

	2. To measure changes in infant sucking behavior during this period, because sucking has been considered a self-regulatory behavior for initiating or maintaining sleep". Recording length: One night at 3 weeks of age, and one night at 5 months of age.	the equipment off at any time they judged necessary". "One community infant was awake or out of view throughout the 5 Week recording". "not much observation time was lost because of the video being switched off or infant behavior being unclear, but parents removed infants from the video recording for substantial periods largely for feeding and care (only 9 of 99 infants were recorded feeding at 5 weeks). This is unlikely to distort the findings reported but is a limitation of the video methods used here". "allowing up to 13 hours of continuous recording... Parents could switch the equipment off at any time they judged necessary". "On an average, video recording at 5W began at 10:20PM and lasted for 9 hours 03 minutes, starting at 9:44PM and lasting 10 hours 09 minutes at 3M, providing approximately 1000 hours of recording per age".		
[32] (Tipene-Leach, Baddock et al. 2018). Sample: 24 mostly indigenous Maori mothers who were referred by local health providers. Infants 1 month old.	Home study of New Zealand indigenous group introduced to a 'sleep pod' device. Unclear methodological details. Recruitment problems. Historical controls.	Digital infrared video camera(s) and recorder(s) (Swann wireless ADW-400; Swann, Richmond, Vic., Australia). Number of cameras based on participant need.	Deductive; Quantitative; Triangulation of methodologies (questionnaires, interviews, oxygen saturation and environmental - bedroom and outside -	Strengths: Hard to reach population. Validated coding scheme. Weakness: Non-contemporaneous

Setting: Home. Outcome variable: Infant head covering, sleep position, sleep location, behavioural arousals, breastfeeding, maternal–infant interactions and direct bed sharing. Funding: Not stated.	"The aim of this study was to identify the potential risks and benefits of sleeping infants in a Pepi-Pod distributed to families with high risk of sudden unexpected death in infancy compared to a bassinet". Recording length: "Physiological recordings between 10 pm and 6 am were analysed. Studies with less than 2.5 h of continuous data were excluded".	Camera positioning: "One camera was above the parental bed, and another, if the infant slept elsewhere, was above the infant sleep device". Operator not stated.	temperatures); Cohort Study.	control bias: Historical controls. Risk of confounding: "Studies with less than 2.5 h of continuous data were excluded" (p3). Risk of starting time bias. No clear recording protocol. Poor recruitment rate (22%). Risk of Bias classification: Moderate.
[33] (Waters, Gonzalez et al. 1996). Sample: Ten healthy infants age 10 to 22 weeks. "Twenty-eight recordings of concurrent, video, and cardiorespiratory variables, were completed" (p620). Setting: Home. Outcome variable: Heart rate (mean, peak, low), respiratory rate (mean, peak, low), apnea, hypopnea, and desaturation indexes (number of events per hour), Sao2 (mean, low), actual Ptco2 (uncorrected mean,	Sought to "determine the frequency and physiologic consequences of the face-straight-down (FSD) position". Infrared video and cardiorespiratory recordings were made on 3 consecutive nights in the prone (nights 1 and 3) and lateral (night 2) positions Rudimentary movement detection technology was used - described as "a computerized movement detection system".	"Infrared video and cardiorespiratory recordings were made on 3 consecutive nights in the prone (nights 1 and 3) and lateral (night 2) positions". "The sound and appearance of each subject were recorded with a low-light, tripod-mounted security camera (Panasonic WVBC 604) under infrared lighting (Minikat Indoor IR light, GTE Products, Toronto, Ontario). The camera was connected to a portable video recorder with a time-date generator (Hitachi Camcorder VM-S8200A). Recordings were made at super-long-play speed, yielding 8 hours of data with one T- 160 tape... Audio signals were obtained from a	Inductive; Quantitative; Triangulation of methodologies (Polysomnograp hy); Cross-sectional.	Strength: validated coding scheme. "Previous evaluation of this method showed a 94% accuracy for detection of sleep". Weaknesses: allocation bias. Starting 'positions' (prone or lateral) were not randomised. Risk of starting time bias. No clear recording protocol. Subjective validation technique: "Our technician rated

peak), movement/arousal index (number of events per hour), and sleep efficiency. Funding: Government, academic institution and non-profit organization.	Recording length: 3 consecutive nights (8 hours each).	unidirectional microphone (Bescor M265) positioned approximately 1 m from the subject's head.". Camera positioned "in the infant's normal sleep environment". "A mirror was placed in the crib to ensure accuracy in determining the relative head and body positions of the infant". "A technician went to the home each night to set up the recording at the infant's usual bedtime and returned the following morning to collect the recorded data". The authors' acknowledge the field of vision may have been compromised as 9 of the 10 infants slept with a cover (sheet or light blanket).		the bedding as firm in nine cases and soft in one case; no predetermined criteria were used for this evaluation". Small sample size. Risk of unacceptability bias. "one infant was withdrawn from the study after the first recording night because of parental anxiety". Risk of Bias classification: High.
[34] Ball.H 2006 Sample: Part 1: 10 twin baby pairs aged between 1 and 3 months. Part 2: 14 twin pairs under 3 months of age. Setting: Home and lab. Outcome variable: sleep states (including AS/QS), sleep	Two-part study exploring the behaviour and physiology of twin babies sleeping separately and together. The first phase of the study was descriptive, designed to obtain data on the normal behaviour of co-bedded twin babies in their home environment. The second phase was experimental, involving behavioural and	Home: 1 "small video camcorder connected to a long play video recorder housed in an attached case... The camcorder's 'night-shot' facility permitted filming in complete darkness" (p406). Lab: 1 "ceiling-mounted camera and infra-red lighting. The direction and zoom of the camera was manipulated remotely from the adjacent monitoring room and the live camera feed was	Deductive; Qualitative & quantitative; Triangulation of methodologies; Cross-sectional.	Strengths: Incorporated inter- and intra observer reliability. Habituation night "to minimise the effect of the camera on behaviour" (p406). Infants used as their own controls.

position, orientation, proximity, movement, safety. Funding: non-profit organisation	physiological monitoring. Recording length, Home: 2 nights (1 used for habituation). Lab: 3 nights (1 used for habituation).	displayed on-screen" (p406). Camera positioning: Home: "The camera was mounted on a 2-m tripod and positioned directly over the babies' cot/moses basket to obtain a 'bird's eye' view" (p406). Lab: Ceiling-mounted and positioned over the babies' cot(s). Camera operator: Home: "Parents were asked to care for their babies as normal, provided with instructions to begin recording (using a remote control) once their babies were placed in the cot for the night, and asked to allow the tape to record unimpeded until the babies were removed from the cot in the morning, or the 8-hour tape elapsed, whichever was sooner. Parents were shown how to use the remote control to halt the recording at any point if they felt it was necessary" (p406). Lab – researchers.		Weakness: Convenience sample. Risk of Bias classification: Low
[35] Ball et al 2006 Sample: 64 newly delivered mother-infant dyads with a	Randomised non-blinded trial analysed by intention to treat. Sought "to determine whether postnatal mother-infant sleep proximity affects	"1 small camcorder with infra-red filming capability". Camera positioning:	Deductive; Qualitative & quantitative; Triangulation of methodologies; RCT.	Strengths: Random allocation to conditions. Equal proportions of tapes coded

prenatal intention to breastfeed. Setting: Clinical (NHS hospital). Outcome variable: Breastfeeding frequency and infant safety. Funding: "Funding was provided by Babes-in-Arms (www.babes-in-arms.org). The funders had no involvement in the conduct of the trial or the writing of this paper."	breastfeeding initiation and infant safety." Infants were randomly allocated to one of 3 sleep conditions: Baby in mother's bed with cot-side; baby in side-car crib attached to mother's bed; baby in stand alone cot adjacent to mother's bed. Offered mothers the opportunity to view their video-tapes and gave mothers a tape of clips from their 2 nights of filming. Recording length: 4-hours x 2 nights of filming.	Camera "erected atop a two metre monopod attached to the foot of the mother's bed with the recorder housed in an attaché case placed under the bed." Camera operator: Participant. "Mothers were provided with a remote control and requested to start the recording whenever they intended to settle down for sleep. The tape recorded for 8 hours or until the mother chose to terminate filming."		from each condition in order to minimise any potential observer bias. Use of inter-rater reliability: "Inter- and intra-observer reliability was regularly tested via re-coding of identical sections of tape to ensure kappa scores greater than 90%." Weaknesses: "Half of all mothers recruited were lost due to ineligibility following delivery" resulting in lack of statistical power. Recruitment rate of 35%. Risk of Bias classification: Low
[36] Volpe et al 2013. Sample: 4 mother-infant dyads. Infants four months old. Setting: Lab. Outcome variable: Sleep-related risks (timing, duration, and patterning of).	4 case studies based on overnight observations conducted with first-time mothers and their four-month old infants. Investigated mothers' strategic management of nighttime parenting. "Studies were selected as case studies based on the occurrence of sleep related practices identified as risks in the clinical literature".	"Infra-red cameras collected continuous video and audio recordings." "When infants and mothers were in separate rooms they were recorded simultaneously using a split-screen format with a digital mixer (Panasonic Digital AV Mixer WJ-MX20)" (secondary source: original thesis).	Inductive; Qualitative & Quantitative; Case study.	Strengths: Use of inter-rater reliability: "All research staff completed an iterative process of comparing coding results with each other until no major discrepancies were found" (secondary source: original thesis).

Funding: Unclear.	Sought to "provide detailed descriptions based on video analysis of four sleep-related risks". Recording length: 1 night.	"Cameras were wired to a Panasonic VHS machine and were recorded in SVHS format using EP (extended play) settings" (secondary source: original thesis). Camera positioning: "mounted in the ceilings of each room" (secondary source: original thesis). Camera operator: Researcher		"Every video tape collected in the study was coded by a pair of researchers working together in order to maintain a high degree of accuracy" (secondary source: original thesis). Validated coding scheme. Weaknesses: Missing data due to equipment malfunction; Significant attrition rate (8%). Risk of Bias classification: Moderate.

For readability, each study will thus forth be referred to by number only when quoted in text. Figure 12 details the heterogeneity and homogeneity of the studies with regard to location (clinical, laboratory, home), design (longitudinal, evaluation[11], cross-sectional, case study, cross-over, cohort, triangulation of methods) and use of automation technology.

Table 6 Summary of methodological details table

Study	Clinical	Laboratory	Home	Longitudinal	Evaluation study	Cross-sectional study	Case study	Cross-over study	Cohort Study	Applies automation	Applies methods triangulation
1			X	X		X					X
2			X	X				X			X
3	X				X					X	
4	X			X	X		X				X

[11] Evaluative research is undertaken to assess the worth or success of something: in this case a technology.

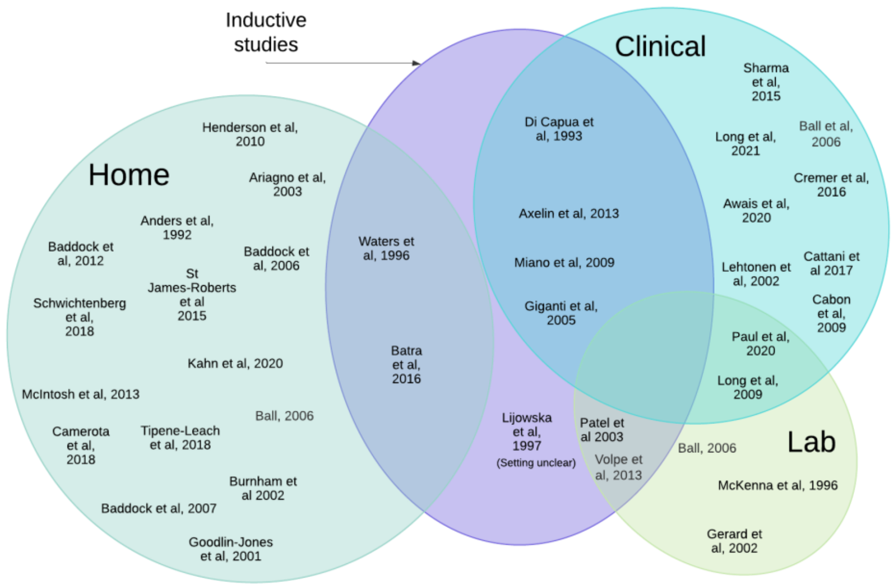
5			X			X					X
6			X	X							
7			X						X		X
8			X	X							
9			X	X							X
10	X			X	X					X	
11			X		X						X
12	X				X					X	
13	X								X		X
14	X			X					X		
15		X				X					X
16	X					X					
17			X	X							X
18			X	X							X
19			X			X				X	
20	X					X					X
21						X					X
22		X			X					X	
23	X				X					X	X
24			X								X
25		X				X		X			X
26	X										X
27		X				X					X
28	X	X			X						X
29			X		X					X	X
30	X				X					X	
31			X	X							X
32			X								
33			X			X				X	X
34		X	X			X					X
35	X					X					X
36		X					X				

The studies' theoretical approaches

Crucial methodological decisions indicate presuppositions concerning ontology — the reality status of the 'thing' being studied (Schwartz-Shea and Yanow 2013). These decisions include when to switch the camera on and off, what to focus on, whether to track the subject or remain in a fixed position, who will operate the camera, and whether to film at close range or from a distance (Lapadat 2000). Such decisions ultimately result in a trade-off between gains and losses in the video representation of the phenomenon. The theoretical approach of the studies was defined as either inductive or deductive. Inductive reasoning aims at developing a theory while deductive reasoning aims at testing an existing theory. Information such as whether hypotheses were given, whether a predefined coding framework was applied or whether codes were derived from the recordings, helped to categorise each study as either inductive (exploratory) or deductive.

Figure 13 shows that most studies (n=25) were deductive. Further, a lower percentage of inductive studies (highlighted in purple) were conducted in the home setting despite being the most common setting.

Figure 12 *Theoretical p*osition by research setting – inductive versus deductive*.*



Inductive approaches are considered appropriate when ‘raw’ video data sets have been collected with broad questions in mind (Jewitt 2012). [4] and [36] provided an example of an inductive approach. The only case studies in the review, codes that emerged from the data included who handled the infant and how.

Research type

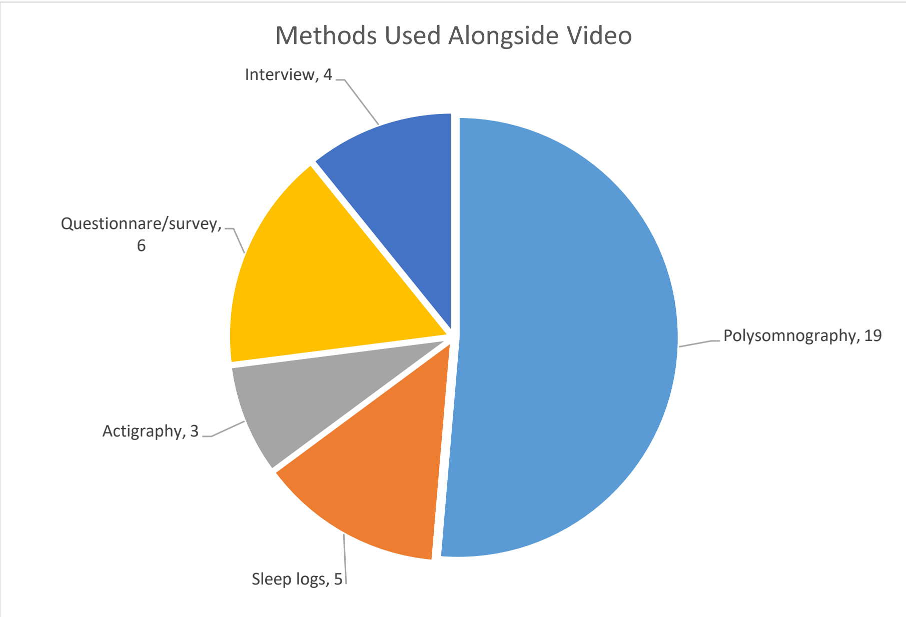
Although video data and its analysis facilitate the integration of qualitative and quantitative approaches, only 18% of studies employed a mixed design and none employed a wholly qualitative design. When using video, a mixed approach can pair systematic quantitative analysis with micro qualitative analysis in order to probe the patterns identified in quantitative results.

Triangulation

Video data provides researchers with the opportunity of attending to the multiple layers of complexity that are inherent in infant sleep, such as content, context and physiology. Indeed, the complexity of sleep lends itself to analysis at many levels using multiple methods. Numerous examples of method triangulation were presented across studies. [11] examined concordance between sleep variables derived from video, actigraphy, and sleep diaries; [9] collected data from video and parental report; and [21] synchronized video with polysomnography (including electrocardiogram, CO2 catheter and a plethysmography band). In that study, a cross-correlational confidence score was used to assess the strength of the evidence for a behavioural occurrence. A score of 3 was used when all methods conclusively indicated occurrence; a score of 2, when evidence for this was strong but one or more signals were indeterminant; and a score of 1, when evidence could be open to question because of absence of a second reliable recording to confirm.

In conjunction with video, the most common supplementary method used to assess infant sleep was polysomnography (PSG) (n=19) (Figure 14). PSG is a multi-parametric test used to record the activity of different physiological factors. It requires numerous sensor attachments to the infant. Examples include electoencephalograms and electrooculograms ([25]), pneumograms ([14]), pulse oximetry ([26]), nasal airflow ([7]), shin and/or rectal temperature ([5]), thoracic respiratory effort [2], and chin electromyography ([28]). Combining video with polysomnography is considered the gold standard for sleep scoring (Berry, Gamaldo et al. 2015).

Figure 13 Pie chart showing triangulation of methodologies.



Disciplines

The majority (n=14) of studies were conducted by researchers situated within the discipline of Medicine ([1], [2], [8], [10], [13], [14], [15], [20], [21], [24], [26], [27], [28], [33]). The remaining authors were situated within the disciplines of Computer Science and Engineering ([3], [12], [22], [23], [29]), Nursing ([4]), Midwifery ([5][6],[7], [30], [32]) and within the social sciences[12], specifically Psychology ([11], [16], [17], [18], [25]; [31]), Education ([9], [19]) and Anthropology ([25], [34], [35], [36]).

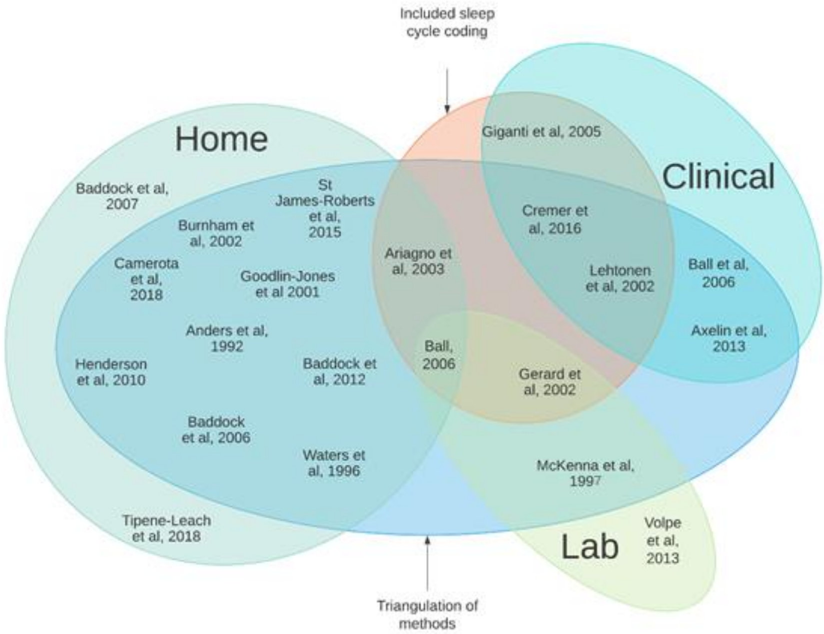
Outcome phenomenon of interest

Studies were heterogeneous by outcome phenomenon of interest – the aspect of sleep focused upon. This factor can be grouped into four groups: Sleep Quantity (duration), Sleep Quality (e.g., awakenings, snoring, apnea) Sleep Architecture (QS/AS, indeterminate), and Sleep Interventions (e.g., factors external to the infant). Studies with multiple outcome phenomena of interest often straddled groups.

Analyses of infant sleep typically involves the examination of sleep 'indicators'. As detailed in the biobehavioural review, physiological and psychological processes cluster and are manifested in behavioural states, such as asleep, active awake, quiet awake, etc. These variables can be measured via different methodologies which exist on a spectrum ranging from the objective to the subjective. Most studies (n=21) relied on visual observation as the primary means to code sleep states (see Figure 15). This approach involves researchers looking for certain indicators (e.g., eyes closed, steady breathing, stillness of body) to code a behavioural state (quiet sleep). It is regarded as the least invasive method of assessing infant sleep (De Beritto 2020).Of the studies that applied this traditional approach, none triangulated it against simultaneous PSG traces, believed to be most robust triangulation method (Ball 2021). Six of the traditional observation studies involved coding of sleep cycle factors (highlighted in Figure 15). Here, the category of ‘sleep’ is broken into sub-categories ‘active sleep’, ‘quiet sleep’, and ‘indeterminate sleep’. Of studies employing visual observation, most (n=13) were conducted in the home (also highlighted in Figure 15). As the infant's usual sleep environment, this setting is considered to optimum in terms of ecological validity (Lewkowicz 2001, Sánchez-Ortuño, Edinger et al. 2010).

[12] As defined by ESRC criteria: ESRC. (2021). "What is social science?"   Retrieved 01/03/21, from https://esrc.ukri.org/about-us/what-is-social-science/, ibid., ibid.

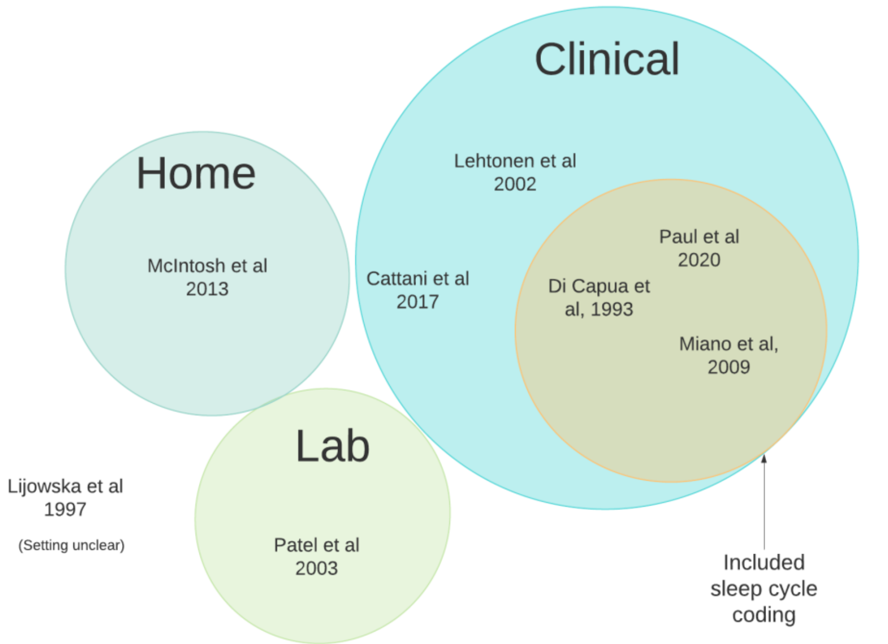
Figure 14 Venn diagram showing studies with primary data from visual video observation.



Aside from sleep state, video data were used to ascertain a wide range of outcomes across studies, with concepts such as 'blanket height' ([5]), 'body and head position' ([5], [33]), 'parental intervention' ([4], [17]), 'environmental risk factors' ([8], [36]), and 'infant self-soothing' ([9]) serving as analytical categories.

In contrast to visual observation, several studies (n=8) relied upon PSG to code sleep states and used video for other variables. Of these, three included coding of sleep cycle states (highlighted in Figure 16).

Figure 15 Venn diagram showing studies with primary sleep data from polysomnography.

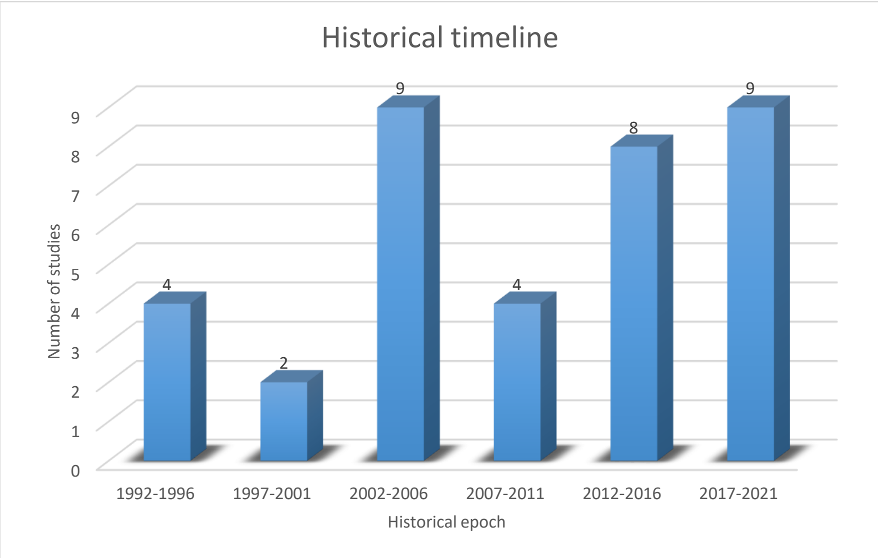


Only three of the studies relying upon polysomnography explained the role of video in their analysis. Video was used to detect eye movements ([20]), and to monitor infant position ([21]). In [27], the infant and polygraph tracing were recorded with an infrared video camera to visually synchronise these outputs for later coding. This study can be contrasted with [4] and [21] which used a split screen monitor to simultaneously display polygraph and infant. Most of the studies using PSG were conducted in a clinical setting (n=5) where such equipment is commonplace, and studies are typically performed by practicing clinicians.

There is significant evidence of collaboration across publications. For instance, in the discipline of Midwifery, Baddock is the first author of three publications [5], [6], [7] and the second author of one other [32] - each study is home-based, deductive and employs visual observation to score sleep. In the discipline of Computer Science & Engineering, Long is the first author in two publications [22], [23], and the second author in one other [3] - each study is clinical, deductive, applies automation technology, focuses on sleep quantity, and has <10 participants. Another example of collaboration within disciplines was seen in Medicine. [21] and [27] share a common author and both studies are inductive, cross-sectional, apply triangulation and use PSG to score sleep. Taken together, these data suggest that, in the field of infant sleep research, theoretical and methodological approaches can become entrenched within disciplines. This amalgamation also indicates that different disciplines bring unique methodological approaches to the study of infant sleep, giving further support to Mileva-Seitz's suggestion of a new concerted field of infant sleep research, Psycho-Anthro-Pediatrics (Mileva-Seitz, Bakermans-Kranenburg et al. 2017). The findings indicate that infant sleep researchers are utilising the academic ecosystem to develop their research through inter-disciplinary collaboration. For instance, Anders co-authored three studies across disciplines, [1] (medicine), [9] (education) and [17] (psychology); notably, despite the projects being conducted a decade apart, are all home-based, deductive, longitudinal and employ visual observation to score sleep.

Historical timeline

Figure 16 Timeline of publications bar chart.

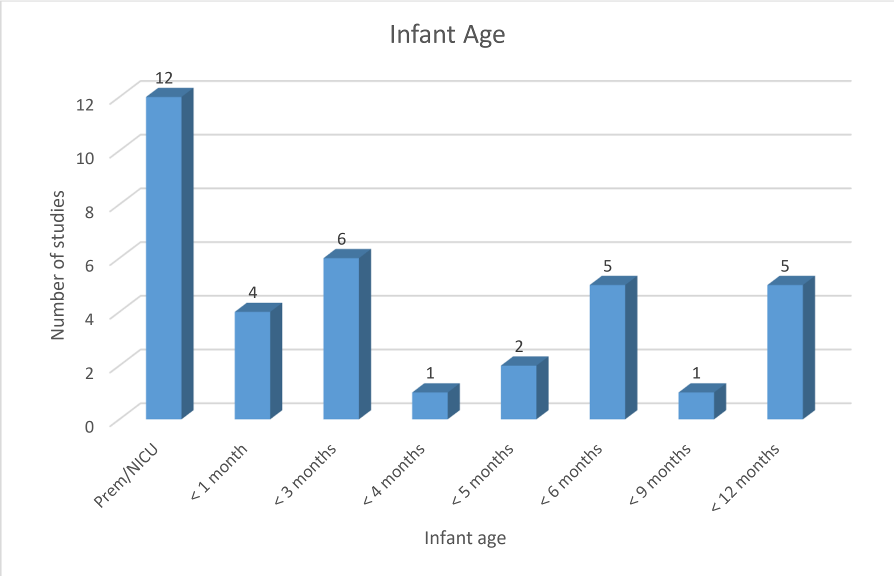


Within the thirty-year inclusion timeframe there were a number of developments in video technology. For instance, emerging formats from VHS to digital have made video data simpler to handle, copy and manipulate. Changes in video use over this time reflect the cost of video equipment and production (Jewitt 2012). The boom in video following the turn of the millennium, clearly reflected on Figure 17, has been termed the "video revolution" (Knoblauch, Schnettler et al. 2006)(p9). This period coincides with an emerging understanding of videosomnography as preferable over other methods for sleep scoring young infants (de Weerd and van den Bossche 2003, Mirmiran, Maas et al. 2003). In the last decade, video has become an easy-to-use omnipresent technology in many people’s everyday lives. This aspect was utilised in [19] where a commercially available smart phone application was used to generate a sample of 1074 participants.

Participant characteristics

The studies selected participants from a variety of age ranges with studies of premature infants being most prevalent.

Figure 17 Infant age bar chart.



Video can open a window into peoples and practices that researchers would not ordinarily be privy to for cultural or social reasons (Jewitt 2012). Three studies accessed traditionally hard to reach minority groups: [25] sampled twenty Latino mother-infant dyads, [32] sampled twenty-four indigenous Maori dyads, and [11] sampled ninety African American dyads.

As detailed in Figure 19, a wide range of sample sizes were observed, with the most common range composing of eleven to twenty participants. Three studies achieved 80% power at 5% level of significance ([5]; [6]; [24]).

Figure 18 Sample size bar chart.

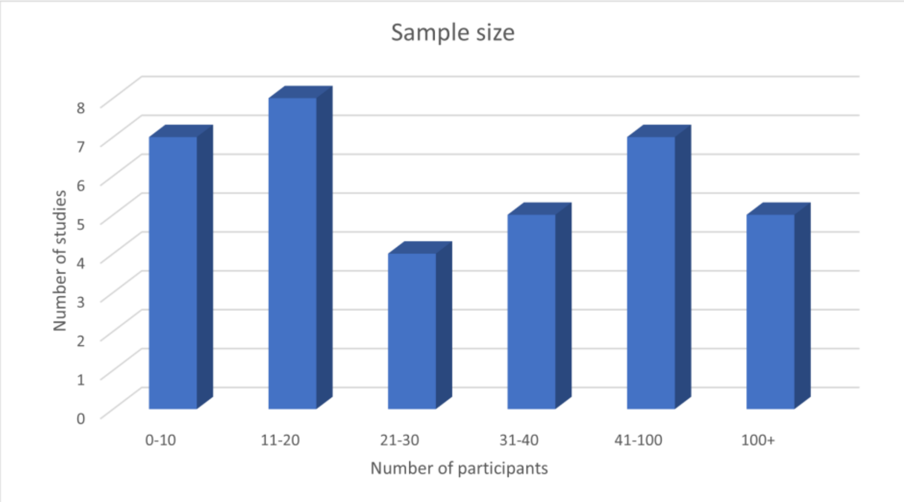
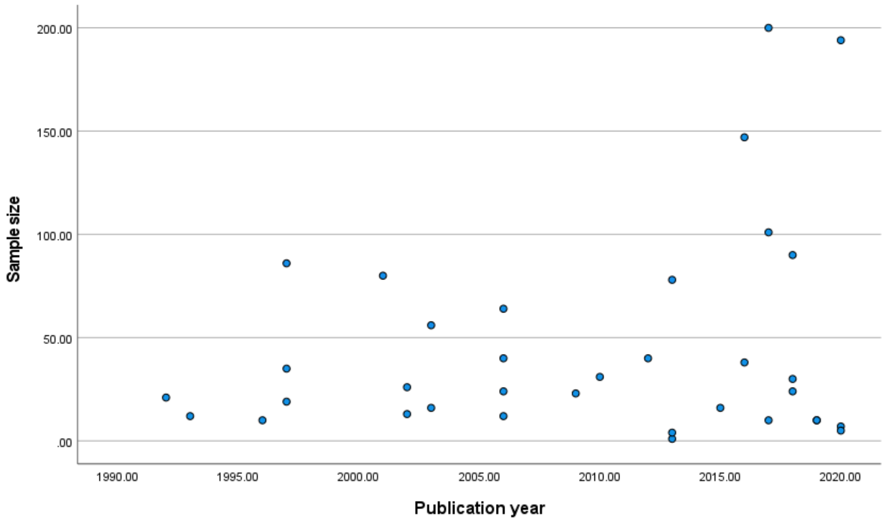


Table 7 Studies by sample size

0-10 infants	*11-20 infants*	*21-30 infants*	*31-40 infants*	*41-100 infants*	*100+ infants*
Awais et al, 2020	Ariagno et al, 2003	Anders et al 1992	Baddock et al, 2006	Baddock et al 2012	Baddock et al 2017
Axelin et al 2013	Cabon, et al 2009	Gerard et al 2002	Cremer et al 2016	Burnham et al 2002	Batra et al 2016
Cattani et al 2017	Di Capua et al, 1993	Tipene-Leach et al 2018	Henderson et al 2010	Camerota et al 2018	Kahn et al 2020
Long et al 2009	Giganti et al 2005	Ball 2006	McKenna et al, 1996	Goodlin-Jones et al 2001	Paul et al 2020
Long et al 2020	Lehtonen et al 2002		Schwichtenberg et al 2018	McIntosh et al 2013	St James-Roberts et al 2015
Waters et al, 1996	Lijowska et al 1997			Patel et al 2003	
Volpe et al 2013	Miano et al, 2009			Ball et al 2006	
	Sharma et al, 2015				

Figure 20 demonstrates an overall increase in sample sizes over time, with a particularly observable increase post-2015. Such increase may have resulted from a progressive reduction in the cost of video equipment over time, a progressive acceptance of video as an appropriate methodology in the field, and/or technological advancements over time.

Figure 19 Scatter plot showing growth in sample size over time (outlier [19] removed)



Camera details

Camera specifications

Type of camera can influence the type of data obtained. This decision can also impact how participants notice or "draw the camera into the research experience" (Jewitt 2012)(p14). Cameras function by capturing light from the visible spectrum as well others parts of the electromagnetic spectrum (GlobalSpec 2021). Capturing phenomena in low-light conditions can be problematic for cameras that require significant levels of illumination. [23] used a monochrome camera with this limitation. In contrast, [9], [17] and [20] used cameras requiring low levels of illumination. Most studies (n=17) employed an infra-red camera. Others (n=5) used an infra-red light-source to reflect light onto the recording area. Several studies (n=7) did not provide any description of the camera/s used.

Camera specifications, such as resolution and frame rate, are important. Resolution is measured with pixels - the higher the number of pixels the higher the quality of image. Four studies gave details of camera resolution. All were in the category of automation studies (discussed later)([10]; [12]; [22], [23]). Of these, [10] gave the highest resolution (720×756 pixels). That study attempted automatic coding of sleep cycle states using a facial reference point. Conversely, [22] gave the lowest resolution (376 480 pixels). That study applied a motion detection algorithm to automatically code sleep vs wake.

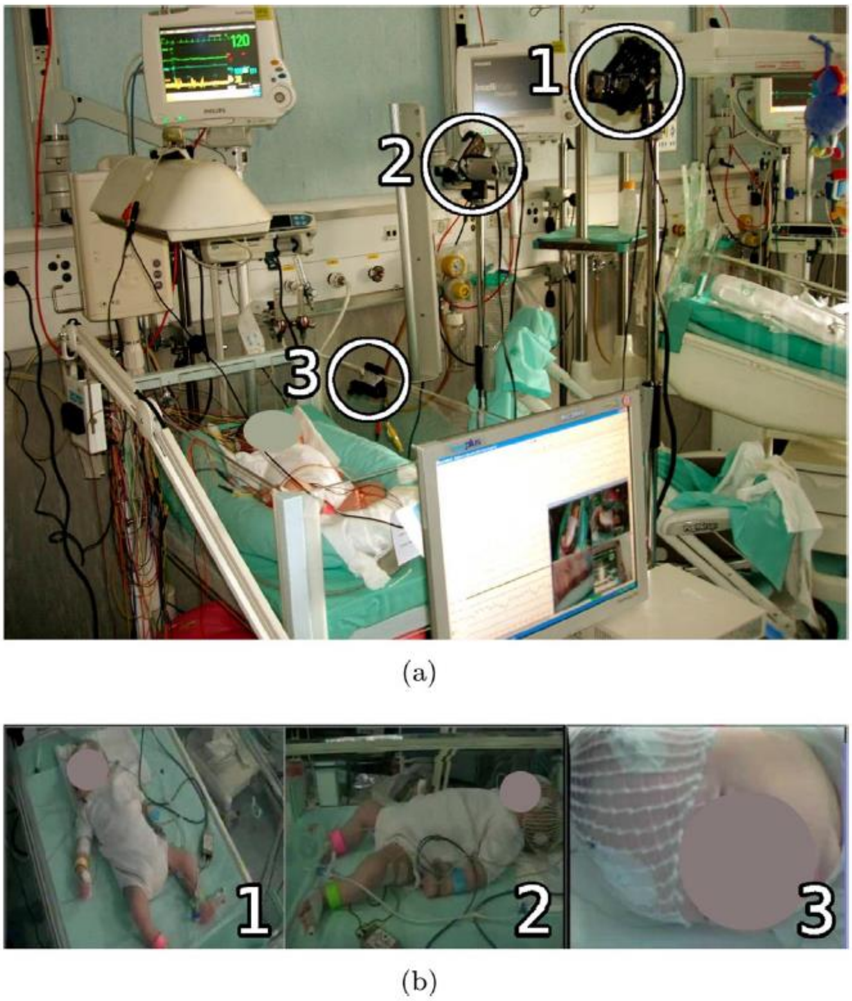
In contrast to resolution, frame rate is the speed at which images are shown. Video cameras record dozens of pictures (or frames) a second. Only three studies gave details of frame rate. All were automation studies ([10]; [12]; [22]). Of these, [10] and [12] gave the fastest rate (25 frames per second) while [23] gave the lowest (8 frames per second).

Another methodological factor that can influence data collection is equipment modification. In this regard, the lens remains the most critical component regarding the quality of video captured (GlobalSpec 2021). For instance, a wide-angle lens can provide more depth of field, meaning that all items in the frame are in focus. Two studies employed this feature ([1]; [9]); both were exploring sleep interventions. To record audio data, seven studies included some form of microphone. Of these, three chose to position the microphone near the bed ([9], [17], [33]), three studies ([1], [10], [11]) used a microphone integrated into the camera, and [21] taped a small microphone directly to the infant's neck.

Number of cameras

Number of cameras varied according to the analytic orientation adopted by the researcher. Multiple cameras broaden perspective, producing a more comprehensive record but can overcomplicate data collection by adding additional perspectives. In this vein, most studies (n=22) employed only one camera. Of these, three ([10], [16], [30]) did not employ supplementary methodologies (triangulation). For studies that utilised multiple cameras, a variety of justifications were given. For [36] the use of multiple cameras enabled researchers to collect data on pre sleep routines spent in a living room, which would have been missing altogether had the present study relied on one stationary camera. [13] used a pilot phase to determine number of cameras. Along with [20], they employed 2 cameras, one to frame the infant body and another positioned closer to frame infant facial details. Conversely, in lieu of split screen technology [15] used one camera to film the infant and another to film the PSG trace. [12] employed 3 synchronised cameras: the first two cameras were arranged orthogonally to frame the infant by the front and the side, and the third camera was attached to the crib to frame the face of the infant (see Figure 21). This approach ensured that all main viewing angles were monitored by different cameras and therefore the system was less affected by the infant's position.

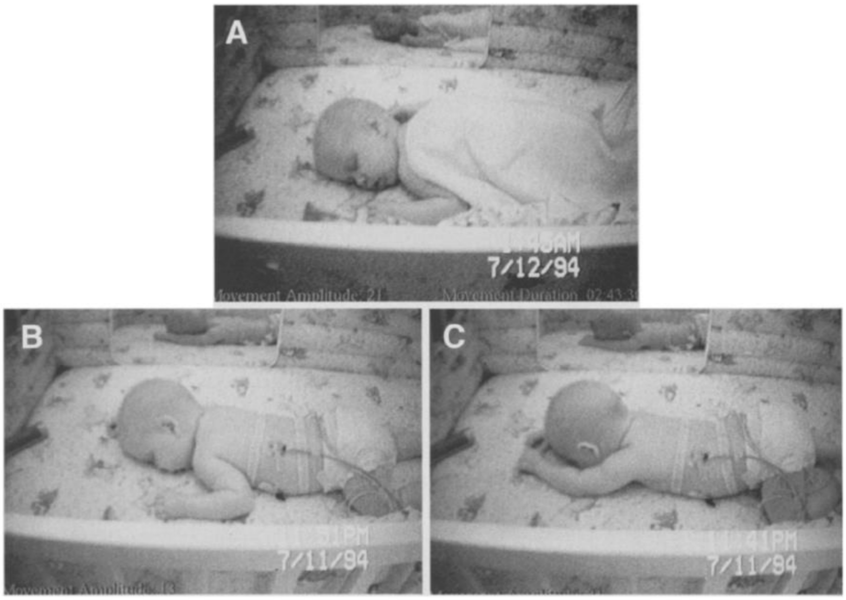
Figure 20 Cattani et al 2017 [12] Use of three cameras



Positioning of the cameras (a) and corresponding screens (b).

Similarly, [33] sought to capture multiple viewing angles. However, as a novel alternative to employing multiple cameras, the researchers placed a mirror in the crib (see Figure 22).

Figure 21 Waters et al 1996 [33] Mirror positioned in crib.



Multiple cameras may be important when the phenomenon of interest includes the surrounding environment and when a conventional framing would undermine analysis. [8] and [32], both home-based sleep intervention studies, selected number of cameras based on participant need. In both studies, one camera was above the parental bed, and others, if the infant slept elsewhere, were positioned at the infant sleep environment. These studies demonstrated that through a multi-camera approach, it is possible to develop an analysis of behavioural sequences between parent and infant even when the two are environmentally spaced.

Recording protocol

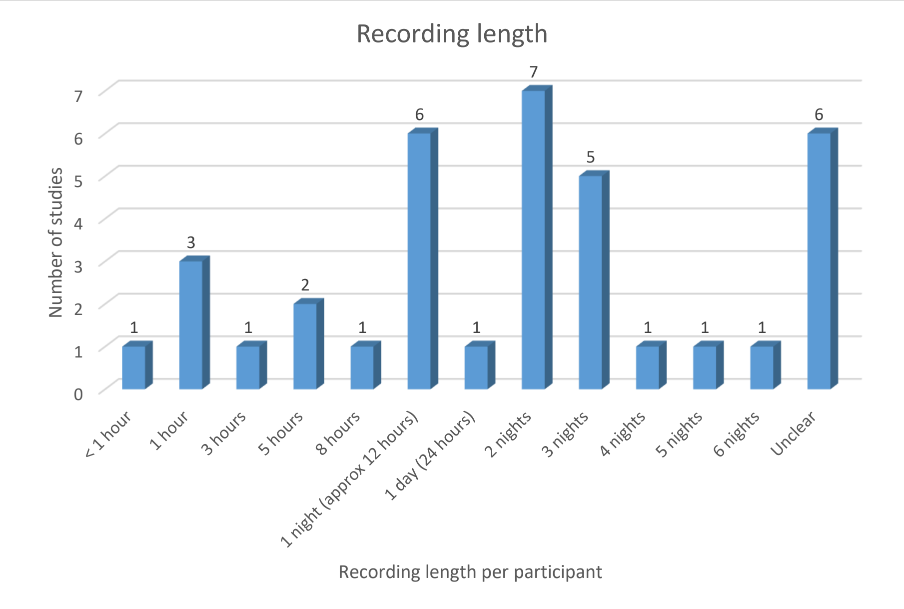
Half (n=18) of studies defined a clear protocol for the start of a recording. Of these, some chose a predetermined time increment (e.g., beginning after the first 5 minutes) or upon a behavioural target (e.g., when sleep begin).

Most studies (n=27) did not mention who was responsible for operating the camera. Two home-based studies ([7], [33]) declared that video was operated by the researcher via periodic home visits to set up and later collect the equipment. Seven studies involved parents activating and deactivating the camera. In each of those, parents were instructed to initiate recording when they began settling their infant to sleep at night and cease recording the next morning. One study ([19]) recruited real-world consumers of a baby monitor device and no recording protocol was given to participants.

Recording length

Video has potential to produce large quantities of data. Across studies, recording length varied from 10 minutes per participant ([10]) to 6 nights per participant ([9]). The most common recording length was 2 nights per participant (n=7 studies). Six studies did not specify recording length.

Figure 22 Recording length bar chart



Positioning of equipment

Nine studies did not provide clear information regarding camera placement ([6], [14], [15], [18], [21], [24], [25], [26], [28]). All remining studies featured cameras in fixed positions, such as mounted upon tripods. Of these, 10 were mounted overhead 'on a stand above the bed or crib' ([4], [5], [7], [19], [16], [17], [22], [29], [30], [32], [34], [35])(see Figure 24), five were positioned 'next to the bed' ([1], [8]; [9], [10], [20]), two were ceiling mounted ([34], [36]), one was positioned 'through the incubators' roofs and/or doors ([13]), and one 'inside the incubator' ([23]).

Figure 23 Baddock et al 2006 [5] camera mounted above sleep space. The most common positioning

Considerations for positioning included 'to observe a major part of the body' ([10]), to observe 'the whole infant's body' [4], or 'to provide a clear view of the primary sleep surface' ([5], [7], [8], [22]). In their evaluation of movement sensors, [12] employed a system composed of three cameras: two cameras arranged orthogonally to frame the infant by the front and the side, and one attached to the cradle to frame the face (see figure 21).

Coding and analysis

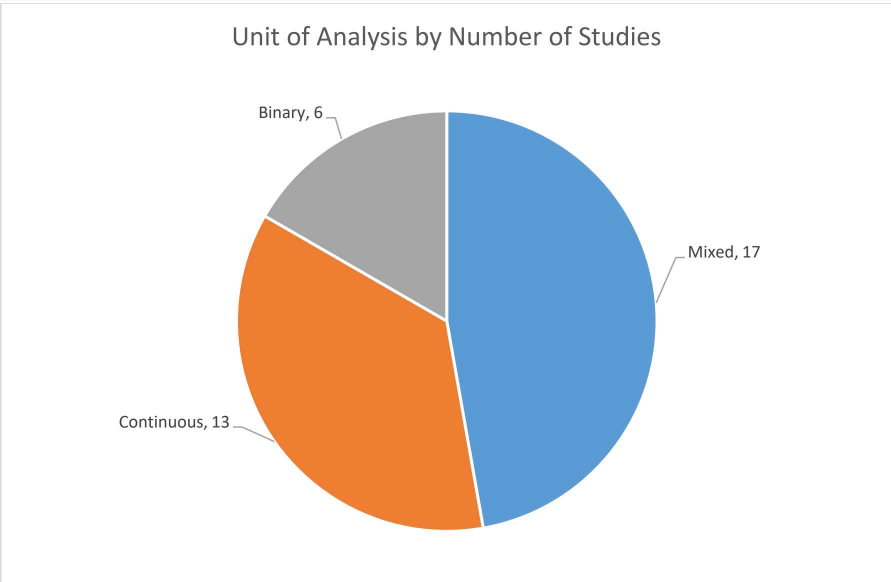
Video data provides researchers with multiple ways of analysing and interpreting infant sleep. One approach is to analyse data 'continuously'. In [5] for instance, start and stop times for behavioural categories were logged over the entire night of recording. A more standard procedure for video analysis is to divide the data into intervals or 'epochs' which can be coded. Across studies, intervals ranged from 10 seconds ([13]; [31]) to 60 seconds ([4], [16], [29]). The most common interval was 30 seconds ([2], [11], [22], [23], [24], [26], [27], [28]).

Intervals can be coded and analysed in two major ways: partial-interval coding and whole-interval coding. In partial-interval coding, the behaviour is coded as having occurred (yes/no) if it was observed at any point during the interval. In whole interval coding, the behaviour must occur throughout the entire interval in order to be coded. When details were given, most studies employed partial-interval coding. As an example, some studies ([16], [31], [24] coded the infant's predominant behavioural state, requiring the state to last >50% of the epoch (either continuously or discontinuously).

Sleep behaviours may further be characterized by duration, frequency, magnitude, and latency. Duration produces an estimate of the amount of time the participant spends engaged in a particular behaviour, for instance, sleep ([5], [18], [19], [34]), seizures ([14]), or in a certain body position ([5], [34]). In contrast, frequency coding involves recording the number of times a behaviour is observed during an observation period. Studies adopting this approach coded feedings ([5], [35]), parental checks ([5], [17]), awakenings ([1], [17], [19]), movements ([20], [22], [34]), startles ([15]) and SIDS risk behaviours ([32], [34], [35], [36]). Behavioural magnitude can be assessed by assigning a rating to the intensity of a behaviour using a rating scale. Coding of magnitude was central to the research aims of [14]. The clinical study sought to distinguish between convulsive sleep disorders (which are pathological and require treatment) and benign sleep seizures (which are rare but considered clinically normal). 'Maximal expression' of seizures was a key variable of analysis. The study also counted from commencement of sleep to the onset of seizures. This variable is known as latency. It provides information about the amount of time that elapses between an environmental event and the start of a target behaviour. Adopting this approach, [14] also counted from onset of seizures to the time to their maximal expression. Similarly, [5] counted time from being placed in bed to falling asleep; and [20] counted the onset of each movement >2 seconds' duration.

Given the heterogeneity of analytical approaches, studies were grouped by unit of analysis to facilitate comparison. 'Continuous' data is typically numeric in value and often referred to as 'duration' data. It can be divided into smaller chunks including fractional and decimal values. Choosing to code continuous data can be useful for small sample sizes and when researchers want to conduct a wide variety of analyses (e.g., [36]). Examples of continuous data include sleep efficiency ([28]), time spent in a position ([7]), prevalent motility pattern ([16]), and comfort object use ([9]). In contrast, binary data can have only two values. It is useful for calculating proportions or percentages, such as the proportion of time spent asleep versus awake. Examples include presence of seizures ([12]), sleep versus awake ([29]), absence of motion ([30]), and eyes open/closed ([21]). Only 17% of studies measured solely binary data.

Figure 24 Pie chart showing number of studies for each unit of analysis



Software

When video datasets are large, systematic observation software packages can assist in storage and management by using time-stamped technologies to link codes. Programs enable simultaneous coding of multiple streams of data recorded in image, including audio, physiological, and other media files. Software cited include Noldus Observer XT ([6], [32], [35], [36]), Bosch Divar XF/700 ([8]), ExacqVision ([11]); Somnologica [2], Sandman Elite V9.2 ([24], or custom-developed software ([5]). After coding, data can be imported into statistical software for further analysis. For this purpose, [9], [31], [35] and [36] cited using Statistical Package for Social Sciences (SPSS).

Review Question 2. How Robust is Videosomnography for Assessing Infant Sleep?

Robustness guidelines

The amassed data will now be examined within and between studies to explore the review hypothesis. This section aims to establish the appropriateness and value of video to each study, to identify, clarify, and review any problems with the processes and instruments, and to identify conceptual, methodological, and practical problems associated with video methodology; an approach recommended for methodological reviews (Lawson, Leenus et al. 2020). The MMAT critical appraisal tool was used to calculate an overall score regarding risk of bias (Pace, Pluye et al. 2012). Studies were categorised as either, 'low risk of bias' (score of >70%), 'moderate risk of bias' (score of 40-70%), 'high risk of bias' (i.e., bias of sufficient magnitude to have a notable impact on the results)(score of <40%) and unclear (judgment is impossible). Following MMAT guidelines, studies with high risk of bias/low methodological quality were included in the synthesis (Hong, Fàbregues et al. 2018). As an extra layer of synthesis regarding qualitative studies, studies were screen through ESRC guidelines where appropriate.

Methodological strengths

Methodological decisions shape the production and interpretation of video data. The most common methodological strengths noted across the studies are detailed in Table 8.

Table 8 Common methodological strengths

Validated coding scheme (n=18)	**Inter-rater reliability (n=17)**	**Adaption period (n=4)**	**Coder/s blind to hypotheses (n=4)**	**Trained coder/s (n=3)**
Miano et al, 2009	Sharma et al, 2015	McKenna et al, 1997	Lehtonen et al 2002	St James-Roberts et al 2015
Ariagno et al, 2003	Cremer et al 2016	Baddock et al, 2006	Axelin et al 2013	Long et al 2019
Waters et al, 1996	Goodlin-Jones et al 2001	Baddock et al 2012	Gerard et al 2002	Cremer et al 2016
Cremer et al 2016	Batra et al 2016	Giganti et al 2006	St James-Roberts et al 2015	

Goodlin-Jones et al 2001	Schwichtenberg et al 2018			
McIntosh et al 2013	McIntosh et al 2013			
Lehtonen et al 2002	Lehtonen et al 2002			
Lijowska et al 1997	Anders et al 1992			
Kahn et al 2020	Axelin et al 2013			
Long et al 2020	Gerard et al 2002			
Tipene-Leach et al 2018	Burnham et al 2002			
Burnham et al 2002	St James-Roberts et al 2015			
St James-Roberts et al 2015	Baddock et al 2007			
Long et al 2019	Camerota et al 2018			
Baddock et al 2007	Ball 2006			
Paul et al 2020	Ball et al 2006			
Ball et al 2006	Volpe et al 2013			
Volpe et al 2013				

When a coding scheme has 'validity' it is deemed to measure what it claims to measure. In this sense, repeated use of a coding scheme in multiple infant sleep studies could be considered a form of inter-rater reliability and indicative of validity. In this vein, two studies drew from other authors' coding schemes in the development of their own ([13], [31]), and three studies adopted others' coding schemes outright ([21], [22], [23]). Cited coding schemes include the Anders' criteria (employed by [13], [14], [31]), Prechtl's criteria (employed by [21], [22], [23]) and the coding rules of the American Academy of Sleep Medicine (employed by [22] and [28]). Other authors were vague in the origin of their coding schemes. For instance, [26] coded "using standard criteria", [20] utilized "widely used criteria", and [2] and [16] coded 'according to criteria in the literature'. In addition to adopting Anders' criteria, [31] utilised "conventional definitions" of infant behaviour states (p326), whereas [32] and [19] cite using coding schemes they had developed themselves in previous study. In contrast, [33] offered quantitative justification for their coding criteria, noting that previous evaluation of the criteria "showed a 94% accuracy for detection of sleep" (p618). Using a coding scheme that others have used before can delimit subjectivity and thus bias, particularly if the scheme is defined as precisely and exhaustively as possible.

Validity of sleep studies can be jeopardised by a phenomenon known as 'first night effect' (Knoblauch, Schnettler et al. 2006). This occurs when behaviour and sleep architecture is altered on commencement of studies as participants adapt to the equipment and/or environment. In the context of infant sleep studies, FNE can materialise through the infant's interactions with affected adults and with a potentially new environment and/or equipment. To mitigate against FNE 12% of studies incorporated an adaption period during which data was not coded. This period ranged from 30 minutes ([16]) to one night ([5], [7], [25], [36]). The two cross-over studies sought to counter FNE by randomizing their starting conditions ([2], [25]).

Many of the strengths across studies concerned the coding process. 12% of studies featured blinding of coding staff to the study hypotheses. This decision can reduce bias that may result from staff having intimate knowledge of certain aspects of the study. Further, half of studies (n=18) used a validated coding scheme. This approach can enhance coding consistency across projects so that past, present and future studies may be compared directly. When sources were given, studies employed the coding scheme of Anders ([13]; [24]; [31]), Prechtl ([21]; [22], [23]), and the American Academy of Sleep Medicine ([22]; [28]). Three studies ([32], [35], [36]) employed their own coding scheme developed for a previous study. 10% percent of studies employed what they referred to as 'trained' coding staff, although the precise meaning was absent. It is possible to infer that trained in this context was synoicous with experienced or senior, as cited personnel included 'a paediatric sleep specialist' ([13], [22], [23]), 'a paediatric cardiologist' ([2]), and 'a professional neurologist' ([3], [4]). Additionally, 42% of studies performed inter-rater reliability tests. This procedure can strengthen validity by assessing the degree to which different coding staff give consistent estimates of the same behaviour.

Methodological weaknesses

In addition to strengths, common methodological weaknesses were noted across studies.

Table 9 Common methodological weaknesses

No recording protocol (n=18)	**No camera positioning protocol (n=10)**	**Significant attrition rate (n=9)**	**Inappropriate method (n=8)**	**Recording length unclear (n=6)**	**Basic data not adequately described (n=3)**	**No coding protocol (n=2)**

Cabon, et al 2009	Cabon, et al 2009	McIntosh et al 2013	Di Capua et al, 1993	Awais et al, 2020	Miano et al, 2009	Batra et al 2016
Sharma et al, 2015	McKenna et al, 1997	Baddock et al 2007	Cattani et al 2017	Sharma et al, 2015	McIntosh et al 2013	Henderson et al 2010
McKenna et al, 1997	Di Capua et al, 1993	Camerota et al 2018	Patel et al 2003	Di Capua et al, 1993	Henderson et al 2010	
Di Capua et al, 1993	Awais et al, 2020	Cremer et al 2016	McIntosh et al 2013	Patel et al 2003		
Awais et al, 2020	Miano et al, 2009	Batra et al 2016	Lehtonen et al 2002	Lehtonen et al 2002		
Waters et al, 1996	Patel et al 2003	Baddock et al 2012	Lijowska et al 1997	Lijowska et al 1997		
Cattani et al 2017	McIntosh et al 2013	Waters et al, 1996	Miano et al, 2009			
Goodlin-Jones et al 2001	Lijowska et al 1997	Ball et al 2006	Paul et al 2020			
McIntosh et al 2013	Henderson et al 2010	Volpe et al 2013				
Lehtonen et al 2002	Gerard et al 2002					
Kahn et al 2020						
Long et al 2020						
Henderson et al 2010						
Gerard et al 2002						
Tipene-Leach et al 2018						
Long et al 2019						
Baddock et al 2007						
Paul et al 2020						

Many of the methodological weaknesses concerned lack of transparency. Absence of a clear recording protocol was the most common weakness, affecting 55% of studies. Such failure to identify a common starting or finish time (sometimes referred to as 'starting time bias') can strongly jeopardise internal validity (Heneghan 2019). Similar lack of transparency was seen in 30% of studies that did not feature a camera positioning protocol and 6% that did not provide a coding protocol. Although all studies cited using video as a data collection tool, the role of this method was not detailed in 9% of studies. The sum of these findings indicates lack of consistency from night to night and from participant to participant, a serious threat to validity.

Recording length was unclear in 19% of studies. Regarding whether recording length was sufficient, several studies were problematic. The length and diurnal/nocturnal character of video-recorded observation should be informed by the phenomenon of interest and the research questions. In their study of car seat inserts, [24] recorded each infant for only 1 hour and reflected that "the mean duration of sleep in the current study was relatively short in absolute terms" (McIntosh, Tonkin et al. 2013)(p330). Likewise, [26] sought to investigate triangulation between methodologies to score infant sleep and apneas with a recording length of only 3 hours (120 minutes coded). Such relatively short recordings are problematic as they do not account for the possibility that behaviours may change based on the time of day (Kopenhaver Haidet, Tate et al. 2009). In [2] and [33], recordings of daytime 'naps' were possibly insufficient to capture the phenomenon of interest (sleep cycling). [2] justified that "a longer overnight home study was impractical and less acceptable to parents" (Ariagno, Mirmiran et al. 2003)(p624). In a similar vein, clinical study [28] justified their approach by noting that shorter recordings have better acceptability for health care settings and daytime studies are more cost-efficient. However the authors also noted that their daytime data included less total sleep time due to "multiple interferences from environmental stimuli" (Paul, Hayes et al. 2020)(p8). Certainly, monitoring over multiple nights is recommended for reliable measures of wake-sleep patterns (Sadeh, Lavie et al. 1991, Acebo, Sadeh et al. 1999) yet 42% of studies recorded less than two nights per participant. In particular, several studies were at risk of FNE ([6], [8], [11], [29], [31], [32], [36]).

Attrition posed another methodological weakness. Night monitoring is a major time investment for parents. A quarter of all studies (n=8) had a 'significant' attrition rate according to a benchmark of >5% found in established guidelines (Bankhead, Aronson et al. 2017). When reasons for attrition were given, several studies indicated 'unacceptability bias'. This problem occurs when measurements which embarrass or invade privacy are systematically refused or evaded. In [33] for example, one infant was withdrawn from the study after the first recording night "because of parental anxiety" (Waters, Gonzalez et al. 1996)(p620). The study sought to determine the frequency and physiologic consequences of the hazardous face-straight-down sleep position. Sometimes unacceptability bias can result from the nature of the recording equipment. In [36] one participant discontinued participation because mechanical problems with one of the overhead cameras caused too much noise for the participant to sleep.

In addition to transparency and attrition issues, methodological congruence posed a significant problem. Also known as 'poor validity of methods' or 'insensitive measure bias', it occurs when an insufficiently accurate method is used to detect the phenomenon of interest such that important differences are not detected (Heneghan and Brassey 2019). When coding sleep states, several studies (24%) employed polysomnography (PSG) in preference over video. However, the validity of using PSG for this purpose is significantly influenced by participant age, for several reasons. Firstly, in infant studies, the sheer amount of polysomnography equipment that must be attached to the infant means normal infant behaviours are affected and normal caregiving activities are hindered. Therefore, while a gold standard for sleep scoring, polysomnography does not allow for sleep to be recorded under naturalistic circumstances. In any event, sleep spindles do not present until 2 to 3 months of age and about 50% of sleep spindles are asynchronous before 6 months of age, 30% at 1 year. Further, slow wave activity does not appear until 2 to 3 months and K complexes do not appear until 5 months (Grigg-Damberger, Gozal et al. 2007). On this basis, a review of position papers from The Pediatric Task Force and the Scoring Manual Steering Committee concluded that PSG "cannot reliably be used to identify neurological deficits or to predict behavior or outcome in infants because of significant diversity of results, even in normal infants" (Grigg-Damberger, Gozal et al. 2007)(p201). Indeed, when examining sleep architecture, PSG cannot solely differentiate quiet sleep and active sleep, meaning that behavioural correlates are necessary (Grigg-Damberger, Gozal et al. 2007). In 2009, one study ([26]) used PSG to score sleep architecture and apneas. Video was incorporated but the authors failed to detail its role. They concluded that analysis of sleep architecture is 'inappropriate' in infants < 3 months, a judgement based on poor validity of methods. More recently, [28] encountered similar problems relying on PSG to sleep stage, citing that "some infants had abnormal EEGs that affected identification of REM" (Paul, Hayes et al. 2020)(p5). Certainly, the first publication to provide PSG reference values for infants was not published until 2019 and was based on a sample of 30 infants (Daftary, Jalou et al. 2019). In contrast, a study using visual video observation to code sleep cycle justified that "eye movements were scored from a high-quality video image because electrographic detection of eye movements is unreliable at this early age" (Lehtonen, Johnson et al. 2002)(p364).

Whilst the visual observational scoring of sleep is time-consuming, a preference for PSG is not necessarily more efficient and can introduce logistical problems, as illustrated in [27]. The authors used one video camera to record the infant and polygraph tracing so that infant behaviours and physiologic recordings were synchronised for later analysis. Then, rather than code the observational video data, the authors relied on pulse oximeter data to code infant movement. When that equipment failed, they relied upon presence or absence of ECG movement artifacts. Further, the authors' dependence on paper polygraph tracings led them to develop a lengthy random sampling procedure, as follows:

> *"Each page of the tracings represented 30-second epochs of the study. We used a random number generator to select a page (www.randomizer.org). If the selected page met control criteria, then we selected that page. If not, then another number was*

drawn until a nonrebreathing page without desaturation was selected. The beginning of the page was used as the control period. This entire method was repeated for each desaturation for each infant using this method" [sic] (Patel, Paluszynska et al. 2003)(p329).

Common factors affecting robustness

This section will explore common issues and themes impacting robustness across studies. The following factors contribute to heterogeneity across studies.

Automation

Researchers have long sought to develop sleep scoring techniques that are less intrusive than polysomnography, less labour intensive than manual observation and that require minimal expertise to interpret. Driven by this goal, nine studies incorporated some form of automated coding. These systems encompassed a variety of computer-based approaches that assign codes to video data without human interaction. Of these studies, seven were evaluating the technology. The remaining two were home-based cross-sectional projects[13]. Techniques included tracking the face or areas thereof (e.g., eyes), and tracking the body or areas thereof (e.g., chest). Several studies utilised machine learning approaches ([3], [10], [22], [23]). Machine learning is a type of artificial intelligence involving the creation of computer algorithms that improve automatically through experience. The algorithms use a database of previously recorded videos and images and automatically compare these to the present recordings. The approach can be problematic as most machine learning databases feature recordings of adults and therefore cannot be accurately applied to infant subjects, as was the case in [3]. In contrast, one study ([23]) trained their algorithm using infants (n=4) and used another infant to test it. This approach, although more robust than using adult images, may still lead to inaccurate coding due to inter-subject variability, for instance, differences in infant weight, age, sleep pattern, arousals, subtle body movements such as jerks and scratches, and even breathing ([22]). Use of machine learning in infant sleep studies therefore remains rudimentary.

The automation studies shared other common methodological problems. Firstly, data are not generalisable, nor are the results of studies evaluating them (Stanfill, Williams et al. 2010). Secondly, automation technology cannot accurately distinguish sleep cycle states (Active Sleep/Quiet Sleep). For example, [10] used facial tracking to correctly distinguish alert states (Quiet Awake and Active Awake) but could not distinguish calm states (Quiet Sleep, Active Sleep and Drowsy).

Thirdly, automation technology is acutely vulnerable to residual noise. In [10], 10% of videos featured infants with "very rapid motions" that led to tracking errors. Similarly, motion detection can capture irrelevant activity, such as nursing staff (as in [23]) and parental activity

[13] The evaluation studies were excluded from assessment of insensitive measure bias, given their design was to test the feasibility of the instruments.

(as in [22]) which can result in sleep being misclassified as wakefulness (false positives). The technology has reduced validity when the field of vision is compromised, as occurred in [33] when 90% of infants slept with a cover (sheet or light blanket). Additional noise and artifacts are easily created by foreground objects (as in [12], [30]). [12] and [29] sought to reduce this problem by using a 'background subtraction method' "to filter out all unnecessary pixels" (Cattani, Alinovi et al. 2017)(p161)(See Figure 26).

Figure 25 Cattani et al 2017 [12] Background subtraction method to mitigate noise.

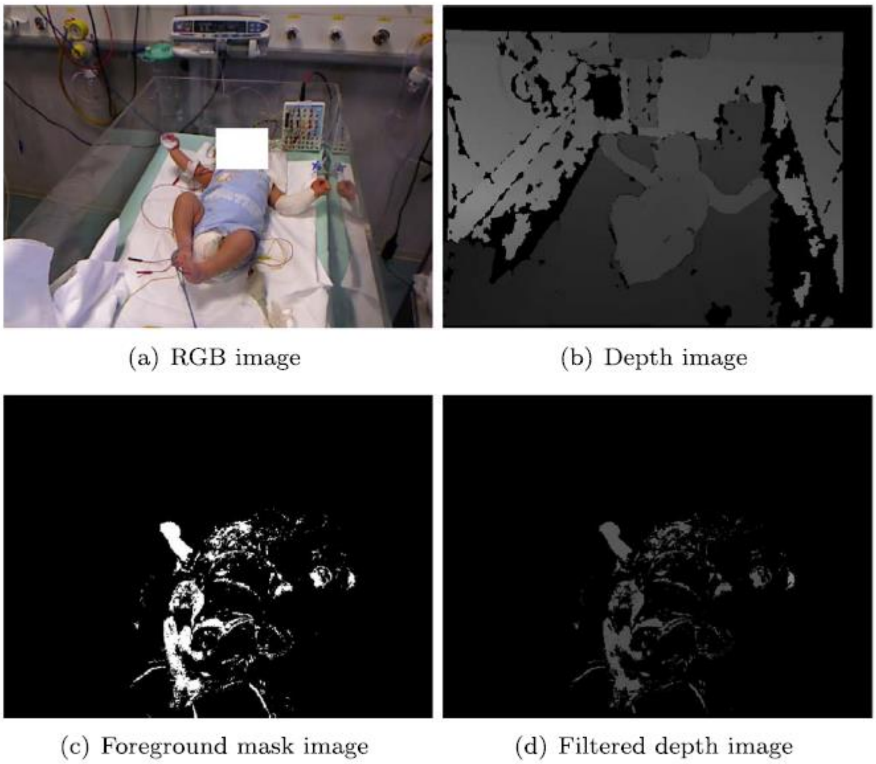


Image (b) illustrates the problem of residual noise. To limit this, a background-fore ground segmentation approach can be used (image c).

Moreover, from an ethical perspective, relative to non-automation projects, studies incorporating automation technology are prone to potential conflicts of interest. The authors of [19], [22] and [23] were employed by a commercial sponsor at the time of writing. Also known as researcher bias, industry sponsorship bias and spin bias (Holman, Bero et al. 2019), this factor can skew the design, conduct and/or publication of research in order to promote commercial interests.

Finally, all automation studies relied heavily on the movement assumptions of sleep. By using movement as a proxy for sleep, the studies were weak at ascertaining non-movement based sleep. For instance, in [22], when performing binary classifications (sleep vs wake) the authors found "overlaps between wake and sleep states which were difficult to correctly identify" (Long, Otte et al. 2019)(p5). The automatic algorithm was apt to misclassify a behaviour as 'wake' when the corresponding PSG suggested active sleep. For the same reason, the algorithm also misclassified 'motionless wake' behaviour as 'sleep'. As one study conceded, "lack of movement is not the same as sleep" (Schwichtenberg, Choe et al. 2018)(p8). In that study, wakings had to include purposeful actions (e.g., sitting up, looking around, crying) meaning that subtle wakings were potentially overlooked. Various techniques were tested to address this problem but with limited success due to the noise created. [30] sought to exaggerate motion by amplifying temporal colour changes, and [12] used a depth sensor to analyse motion data from multiple video sensors placed around an infant. The authors of the latter found that performance improved somewhat with increasing number of cameras.

In summary, studies employing automated algorithms may have utility for discrete binary markers of clinical sleep pathology such as apneas and seizures, however, remain problematic for scoring sleep states given their reliance on movement. They are not useful for conducting behavioural analyses.

Table 10 Summary of automation studies

Study	**Automation technique**	**Problems**	**Recommendations**
Cabon, et al 2009	"Three descriptors were extracted from audio and video recordings: vocalizations, motion and eye state of the baby. For this purpose, an original semi-automatic algorithm for the estimation of the eye state was proposed. Secondly, the three descriptors were used in order to obtain an estimation of the behavioral sleep states". Finally, "five different machine learning approaches" (K-nearest neighbors, linear discriminant analysis, support vector machine, random forest and multi-layer perceptron) were compared to an expert annotation (p365).	In 10% of videos "the baby had very rapid motions that led to tracking errors" (p367). Hidden eye was a significant problem affecting 10% of data. Could not code sleep cycle states. "These results are not surprising considering that Drowsiness is an intermediate state by definition, and that	Previous authors have asserted that the application of automated sleep staging in a realistic hospital environment is not directly possible (Cabon, Porée et al. 2019). This remains an accurate statement with regard to AS, QS and Drowsy.

		QS and AS are close in terms of behavior" (p367).	
Sharma et al, 2015	Sleep apnoea detection method "specifically targeted for newborns" (p3). Use of an automated algorithm to detect absence of respiratory (Pearlman 1979) motion. "Proposed method first applies motion magnification. Subsequently, it filters respiration motion using dynamic thresholding" (p1). Unlike Cabon et al 2019 (above), "This technique does not explicitly estimate motion, but rather exaggerates motion by amplifying temporal color changes".	When amplification is set too high, this can increase noise and other artifacts.	An optimum threshold of amplification has not been ascertained and presents an avenue for future research. "Feedback for its [the algorithm] refinement, along with considering its sensitivity towards illumination changes and other noise factors, need to be checked" (p7).
Awais et al, 2020	Uses 'convolutional neural networks' (CNNs), a form of deep learning whereby a software algorithm analyzes visual imagery. Study used face detection "to evaluate the use of pre-trained convolutional neural networks (CNNs) as a features extractor followed by the Principal Component Analysis (PCA) to find the best discriminant features to perform classification using support vector machine (SVM) algorithm for neonatal sleep and wake states".	Overall performance was described as "quite modest" and "low" when used to classify neonatal sleep and wake states (p3). "Accuracy, sensitivity, and specificity of 65.3%, 69.8%, 61.0%, respectively" (p1).	"This research could be helpful for future studies to adopt other techniques to classify neonatal sleep and wake states using video frames to achieve better accuracy" (p5).
Waters et al, 1996	"Videotape recordings were later played into a computerized movement detection system (SleepVision, Martinex, Montreal, Quebec). This system detected and quantified movements by sampling video signals from the video tape once per second and subtracting each video frame from the preceding video frame to calculate a movement amplitude" (p617).	Authors acknowledge the field of vision may have been compromised as 9 of the 10 infants slept with a cover (sheet or light blanket).	

	"If the movement amplitude exceeded a user-defined value, both video frames were stored on the computer disk" (p617). "Previous evaluation of this method showed a 94% accuracy for detection of sleep" [versus awake] (p618).		
Cattani et al 2017	Proposal of "a monitoring system based on the detection of pathological movements, characterized by the presence or absence of a significant periodic component (i.e. rhythmic movements)". A depth sensor (Microsoft Kinect) connected the video stream to "analyze the data obtained from multiple video sensors placed around a patient, extracting relevant motion signals and estimating, using the Maximum Likelihood (ML) criterion, their possible periodicity... Data fusion principles are considered to aggregate the signals" (p158). "The obtained results show that a video processing-based system can effectively detect the considered specific diseases, with increasing performance for increasing number" [of cameras] (p158). Employed three cameras. "A multi-sensor system is less affected by the patient's position, because all main viewing angles are monitored by different sensors" (p161). Analysis involved "a binary test, which classifies results as "presence of clonic "seizures" in the video of the newborn (positive) and "absence of movements or presence of	Residual noise described as "a significant and systematic issue.. This problem, common to all structured-light approaches which use an offset camera to determine a depth map, consists of the presence of regions where the projected pattern is shadowed by foreground objects, making it impossible to estimate the corresponding depth. Because of this issue, it becomes difficult to apply a simple difference between consecutive depth frames: in fact, in the processed image, besides movement parts, background areas could not be correctly detected" (p160-161).	

	random movements" (negative)" (p161).		
Schwichtenberg et al 2018.	Sought to build upon "the most established signal processing approach - specifically a frame-by-frame differencing approach" and apply it to existing pediatric VSG data" (p2). Movements were assessed using "a background subtraction method". Very similar to Cattani et al (2017). Compared with videosomnography and actigraphy. Minute-by-minute estimates demonstrated "moderate" agreement across compared methods.	"High sensitivity for sleep but only about half of the wake minutes were correctly identified" (p1). "Strongest agreement for sleep onset and offset" (p5). "However, nighttime waking agreements were poor across both behavioral videosomnography and actigraphy comparisons" (p1).	"Further research is needed to identify why some infants were accurately captured and others were not" (p10). "Future studies of auto-VSG systems can build on this study in several ways. First, the classification of infant sleep as sleep or wake is an oversimplification and future studies should code for either sleep stages or consider adding active and quiet sleep states" (p10). "Additionally, future signal processing systems should incorporate all available data including the audio signal. Incorporating the audio signal may allow for more nuanced codes of wake settled or wake distressed and may help disentangle intermediate sleep states" (p10).
Kahn et al 2020.	'Nanit baby monitor' mounted above the infant's crib, continuously recording motion at a pre-defined nighttime period, Infant sleep data "were collected using the Nanit algorithm from the consecutive 14-day period prior to survey completion" (p4). "Whereas actigraphy records the movement of the ankle or wrist, auto-videosomnography system	The app's algorithm was previously validated only on a small sample size "against polysomnography as well as actigraphy, in seven healthy infants aged 0–24 months" (p4). Algorithm does not distinguish sleep states (AS/QS).	

	records movement of the entire body" (p4). "Auto-videosomnography showed adequate sensitivity (75.2% for polysomnography and 73.3% for actigraphy) and excellent specificity (89.1% for polysomnography and 87.9% for actigraphy) in appraising infant sleep" (p4) - but no comparisons to traditional visual video coding.	“Assessment of nighttime—but not daytime—sleep" (p4). Relies on movement so weak at ascertaining non-movement based sleep. "This study was supported by Nanit" - the video recorder manufacturer(p9). "Conflict of interest statement. M.K. and N.B. have served as consultants for Nanit. A.G. was an employee of Nanit at the time of study implementation. M.G. has served a Pro-Bono consultant for Nanit" (p9).	
Long et al 2020	Study evaluated feasibility and performance of video-based actigraphy in identifying sleep-wake states in preterm infants. A uEye Monochrome video camera (IDS GmbH), placed inside the infant's incubator (see Figure 27). "A spatiotemporal recursive search algorithm detected motion, unaffected by illumination changes, from the video frames" (p1). "Video-based actigraphy was computed in a similar way to	"The detection of sleep and awake performances showed noticeable, relatively large variations across the infants. Cohen's kappa ranged from 0.33 to 0.73, overall accuracy from 85.6% to 96.5%, sensitivity from 41.3% to 88.6% and precision from 41.9% to 78.3%" (p1). "The motion detection also picks up other activity	"A larger dataset with a wider age range and longer recording time and polysomnography-based scoring are necessary to verify the proposed automatic sleep-wake detection model" (p2). "Methods that exclusively detect infant movements need to be investigated" (p2). "We used a monochrome camera that required sufficient illumination. An infrared camera should be used to monitor infants in the dark, for example in a covered incubator" (p2).

	actigraphy, by counting the non-zero motion values for each epoch. The activity count was then statistically compared between the sleep and wake epochs" (p1). "Failed to identify being asleep with increased activity or being awake with reduced activity" (p2).	outside the incubator, such as nursing staff, and this can result in sleep being misclassified as wakefulness" (p2). "We used a monochrome camera that required sufficient illumination" (p2).	
Long et al 2019	Used a motion detection algorithm to automatically code sleep vs wake. Compared this with polysomnography (PSG) - based human scoring. The PSG was able to code more nuanced behavioural states whereas the motion detection algorithm was only able to code binary sleep vs wake. "To obtain video-based actigraphy, we employed a spatiotemporal-based recursive search (RS) motion detection algorithm to quantify motions from videos" (p3). "Compared with other motion detection algorithms, such as optical flow, this RS algorithm has been shown to be robust to scene changes, or more specifically in this case, to changes due to illumination, which can be eliminated" (p3). "We calculated the mean activity count (mACT, i.e., count of non-zero motions) over video frames for each epoch, similar to wrist actigraphy. A disadvantage of mACT is that it is challenging to identify wakefulness when body movement is reduced. Therefore, we characterized the "'possibility" of being asleep (pSLP)	"False negatives mostly corresponded to wake epochs with little or even no infant body movements" (p5). For one infant, "video inspection showed this baby was taken out of bed for around one-fifth of the video recording, during which the PSG was still available with wires connected, whereas the infant was not visible through the video camera" (p6). Misclassification of some sleep epochs as wake (false positives) due to external disturbances and inter-subject variability. The algorithm was apt to misclassify a behaviour as 'wake' when the PSG suggested the behaviour was active	"Besides physical activity, vital signs such as respiration and heart rate (and heart rate variability), that are able to characterize autonomic nervous activity, are then required for further improving the classification" (p7). "Advanced video processing and machine learning algorithms to deal with these challenges merit further investigation" (p8). "In addition to validation, future work could focus on the type and quality of movements during in bed periods to help in detection, monitoring, and classification of sleep-related movement disorders, such as restless legs syndrome, periodic limb movement, night terrors/nightmares, head banding, excessive somnolence, insomnia, jet lag syndrome, and sleep-disordered breathing" (p8).

	before and after a very high activity level" (p3).	sleep. For the same reason, the algorithm also misclassified 'motionless wake' behaviour as 'sleep'.	

Environment

The significance of a behaviour is embedded within the environmental circumstances in which it is produced. Accordingly, the phenomenon of interest and the research questions should determine the most appropriate research setting. For instance, [35] avoided certain ethical considerations by collecting data in a laboratory environment; In order to mount cameras in the home, informed consent documents would have needed to be provided to any persons who might possibly have come on-camera.

Flexibility in the implementation of video methodology may be necessary to suit a particular setting (e.g., NICU) compared to another (e.g., the purpose-built sleep lab). [28] used a laboratory for some participants and a NICU ward for others. Data recorded in the laboratory yielded much higher total sleep time than those in the ward, illustrating environment as a confounding factor. Indeed, certain environments contain factors that are difficult to control for. NICU for instance, may have ventilated infants and those on various medications (as in [20]) or regular nursing procedures causing personnel to obscure the camera frame for some infants (as in [13], [16], [23]). In [28] a number of infants had nasal tubes, the presence of which seemed to affect total sleep time.

Within the domestic context, behaviours can be recorded in their naturalistic environment. These studies can provide a window into the private worlds of the intended participants. Of the home studies, five ([5], [7], [25], [32], [36]) specifically detailed bedsharing, a culturally stigmatised activity (Ward 2015, Tomori, Palmquist et al. 2016). Nonetheless, although video cameras are considered "easy to use" in the home (Long, Otte et al. 2019)(p1), the setting is not without methodological limitation. Researchers may not be in control of the recording equipment during data collection and addressing technical issues or performing certain bias-reduction steps such as blinding may therefore be impossible.

Camera positioning

A technical effect of video methodology relates to how the camera ‘participates’ in the production of the record (Jewitt 2012). Where details were given, all studies featured cameras in fixed positions. This restricted their use to stable interactions between subjects within a designated field of vision. The most common camera positioning was overhead on a stand above the bed or crib (n=13). In this vein, [16] placed their camera 1m above the incubator, and in [13], video recordings "were taken through the incubators’ roofs and/or doors" (Cremer, Jost et al. 2016)(p519). In contrast, [23], placed the camera inside the infant's incubator as shown in Figure 27.

Figure 26 Long et al 2020 [23] Camera positioning

A similar configuration resulted in [13]. In that study, initially a single camera filmed from above for a view of the whole infant body. After a pilot phase, infants were filmed with an additional closer camera focusing on the face for better examination of the eyes (for active sleep scoring). Choosing to observe at close range may capture the fine detail of facial expression and gesture but inevitably loses contextual information. Participants can move from the frame at important moments of transition so that critical aspects of an activity are missing. In their study of self-setting behaviours, [31] fixed a camera on a tripod directed at the infant's usual night-time sleep location. Parents removed the infant from the video recording 'for substantial periods' largely for feeding and care. Similarly, in [22], one of the ten participants was taken out of bed for 'around one-fifth of the video recording', during which the PSG was still recording with wires connected, but the infant was not visible in the video frame. In contrast, [9] used a wide-angle lens so that data could encapsulate more of the local environment. No studies used a 'roving' camera, technology designed to enable researchers to react to the circumstances occurring in a setting.

Not only does camera positioning give "a sense of the relationship to the event being established", it also influences the type of data that is obtained (Jewitt 2012)(p15). In this vein, robust methodological decisions require an understanding of the research setting. Observation of the context and phenomenon of interest prior to video recording can help to determine optimum camera positioning. This procedure was performed in the NICU study [13]. There, a curtain was installed to shield the incubator from direct sunlight, in order to reduce reflections and limit alterations of light conditions which can impact camera functioning. When a visual survey of the environment is not feasible prior to the study, participant surveys and interviews may be useful. To guide camera placement, [8] and [11] probed caregivers about the infant's sleep locations, as well as any other areas of the home where the infant and caregiver might spend time together before bedtime or during the night.

Triangulation

Video data is partial - it is focused on the visual material world. Consequently, it includes and excludes variables. To broaden an enquiry, video can be triangulated with other data collection instruments. Some methodologies however are arguably better suited to triangulation with video than others. For instance, video cannot solely determine when a subject is sleeping, given the limitation of visual cues as a sole criterion for sleep. However, when combined with plethysmography (e.g., respiratory frequency) behaviours can be cross-matched and internal validity strengthened. In contrast, movement-based methodologies, such as actigraphy, are shown to significantly overestimate sleep period duration and underestimate the number of night waking episodes compared with video (as examined in [11]). Choice of triangulating methodology is therefore pivotal to study outcomes. It is difficult to separate aspects of behaviour that are natural from behaviours that result from a data collection tool. As discussed, PSG was the most popular supplementary data collection tool across studies (n=19). However, PSG may be impractical in some environments such as the home, and attaching intrusive sensors to an infant's fragile skin may cause discomfort and disrupt sleep (Long, Espina et al. 2020).

Coding and analysis

Two aspects of coding were observed to impact analytical robustness: coding scheme and coding technique. Regarding coding scheme, the validity of 'bespoke' coding schemes may be unknown, because validity is typically not determined for measures created for use one a single study. While some studies used pre-established schemes drawn from their discipline, others built codes from the literature regarding their phenomenon of interest, and others still from the data itself. On a macro scale, it is imperative that coding schemes are written comprehensively enough to determine when a behaviour is engaged and to discriminate between instances of behaviour. In this vein, [10] posed risk of bias by subjectively coding intermediate states which were deemed too difficult to objectively detail in the coding scheme. Worse still, [8] and [18] failed to give any coding protocol.

Regarding coding technique, a measurement of time must be recorded to enable efficient coding of audio and video tracks, and to synchronise video with supplementary methods. Several studies ([1], [5], [7], [17]) recorded clock time onto the video with a time-code generator. In contrast, [25] placed a large digital clock in the camera field to calculate data to the nearest minute. Yet relying upon a digital clock for time data meant that intervals < 1 minute could not be coded as this was below the resolution of the digital clock. This is problematic given the research aim was to explore duration of breastfeeding behaviours, which are potentially short and sporadic. The study illustrates how decisions of camera type and positioning cannot be divorced from the ways the data is subsequently analysed.

Another drawback of video as a rich data collection tool is that it is time-intensive to collect, review and, even with appropriate software, to analyse. Relatedly, the most common analysis technique across studies was interval coding. This pragmatic approach runs the risk of fracturing representations and can "limit (even distort) understanding" (Lemke, 2009, as cited in Jewitt 2012)(p5).

Typically, interval coding is only useful when the target behaviour occurs at a moderate but steady rate (for instance, sighs and startles, sleep cycle states) because interval coding tends to over- or underestimate the actual frequency of behaviours. In partial-interval coding for instance, one event can only be coded once per interval and this can lead to inaccuracy if events change faster than the defined intervals last (Walpusky & Sumfleth, 2009, as cited in Harris 2016). Error rates are particularly high when the total bout lengths of behaviours are short (as in parent-infant interactions) and/or when interval length is long (Mann, Ten Have et al. 1991).

The problem was illustrated in three studies. [16] conducted off-line minute-by-minute analysis of infant activity. Each minute of the recording was classified according to the prevalent state (the one shown for the majority of the time of that minute, either continuously or discontinuously), meaning that non-prevalent but potentially significant states were discarded. [31] conducted a similar time-sampling approach to code infants' predominant behavioural state in each 10-second clip, and [17] in the longitudinal infant self-regulation study. In the latter, an awakening was coded as 'vocalized' if the infant cried, cooed, or babbled and was audible on the videotape recording. For pragmatism, the researchers conflated each of these variables into one category 'vocalized', a decision that imposed limitations on the analysis. As the authors reflected, "the vocalizations noted at 12 months of age may be of a babbling nature and not requests for parental assistance to return to sleep" (p9). These examples demonstrate the subjective character of video, that the same piece of material can be transcribed in many ways. Coding is thus a vehicle through which analytical insights can be gained and certain details are lost (Lapadat 2000). Two studies ([10], [27]) illustrate this dynamic. Both used a random time sampling interval technique. This approach is particularly problematic when compared with continuous recording for estimating actual durations or frequencies of behaviour. Often, very little of the total recording time is coded, and it is possible that a behaviour might occur during every interval other than the one/s selected.

Social science studies

In addition to the Mixed Methods Appraisal Tool (MMAT), the ESRC guidelines for video methodology are applicable to studies that fall under the paradigm of social sciences (n=12). The ESRC identifies three features of video data that "underpin its distinctive potential for social science research", namely 1) its character as a real-time sequential record; 2) as a fine-grained multimodal record; and 3) its durability, malleable, and share-ability (Jewitt 2012)(p4).

1) a real-time sequential record

The ESRC considers this quality of video as "essential" for the study of naturally occurring data (Jewitt 2012)(p4). It refers to the ability to represent the order events in a manner that is "in sync with the meaning of events" and "truthlike" (Goldman, 2009, as cited in Jewitt 2012)(p5). Examples of this quality were seen in several studies examining interaction between infant and caretaker. [25] was the first known study to include a bedsharing environment.

Conducted in a laboratory, the researchers examined awakenings for breastfeeding. Similarly, [17] examined nocturnal vocalized awakenings in the home setting. Each used video to capture a temporal and sequential record of events, aspects that are deemed “so characteristic of interaction” (Knoblauch, Schnettler et al. 2006)(p19). In a similar vein, [16] and [19] utilised the sequential quality of video data to examine infant sleep–wake patterns in response to two interventions - screen time and NICU staff engagements, respectively. Similarly, [36] recorded infants and mothers simultaneously, even when they were in separate rooms, by using a split-screen format with a digital mixer.

Sequential phenomena are easily captured and analysed by video as data can be slowed down or sped up to see infant sleep behaviours in new ways. In this respect, [17] and [9] used 18hr time-lapse modes recorded on a single one-hour reel of VHS videotape, with both applying a time code generator to record real clock time on the tape. Slowing down and speeding up video in this way can 'denaturalize' it, thus helping researchers to gain analytical distance and reflexivity (Lemke 2009).

2) a fine-grained multimodal record

The ESRC describe this quality of video as ‘wholeness’ and claim it cannot be provided by any other technology. The term refers to ensuring that a record is sufficiently detailed to capture "the essence" of a particular event (Goldman, 2009, as cited in Jewitt 2012)(p5). In this respect, [36] investigated mothers' strategic management of nighttime parenting. Their detailed case studies provided deep insight into private and controversial processes not acknowledged by present risk-reduction campaigns; including for example, sofa sleeping and unsafe bedsharing. In that study, when audio data were compromised, visual cues were used. Certainly, video can illuminate the multimodal character of behaviour and social interaction, potentially detailing gaze, expression, body posture, gesture and tone. [16] utilised this strength to evaluate infant body motility patterns, [25] to explore breastfeeding behaviour, and [9], [17], [18], and [31] to examine infant self-regulating behaviours.

In capturing the wholeness of behaviour, choosing the appropriate camera specifications are of critical import, particularly in nocturnal settings. In this respect, [17] used a low-level illumination camera, [11] used high-definition cameras, [9] used a camera with wide angle lens and an auto-focus, six studies incorporated infrared technology ([9], [11], [31], [34], [35], [36]), and two studies incorporated a microphone ([9], [11]).

Another way to ensure that the video record is sufficiently detailed is to use multiple cameras. [11] and [36] were the only social science studies to do this (four cameras). In [11], camera placement was determined after dialogue with parents. Conversely, in [31] parents removed infants from the view of the single camera for substantial periods leading to missing data. The remaining studies relied on one camera supplemented with other methodologies, commonly parental questionnaire (n= 3 studies) and parental sleep logs (n=5 studies). This triangulation approach recognises that video data does not record a social situation rather it records the "visual impression of a situation" (Schindler, 2009, as cited in Jewitt 2012)(p11). Of the studies with one camera, only [16] did not employ supplementary methodologies. That study sought to evaluate infant behaviour and interventions (medications, feedings, etc.) within a NICU.

Recording with one camera and without supplementary methodologies could be problematic given the approach may fail to capture important contextual data.

The potential wholeness of video data positions the methodology as superior in the study of sleep states. As discussed, whilst movement is a useful indicator of wakefulness, active sleep and wakefulness cannot be differentiated without the observation of at least one more behavioural parameter, such as eyes open (Ficca, Fagioli et al. 2000). This was illustrated in [11] who compared video with actigraphy and self-report. The study concluded that, as video makes use of multiple cues when coding states, it is more sensitive than other methodologies. In a similar vein, [16] was one of the few clinical studies to distinguish active sleep and quiet sleep. It was also the first study to provide exhaustive descriptions of wakefulness states in premature infants. For instance, the coding scheme was able to detail that, "gross generalized body movements with prolonged startles, marked stretching and writhing was considered as waking, whereas vigorous, forceful abrupt body movements with high frequency tremor sometimes superimposed upon movements were considered as corresponding to crying" (Giganti, Ficca et al. 2006)(p435). In [9] body movements of interest, ranged from small twitches of fingers and feet to gross writhing movements and starts. Both studies illustrate a virtue of video methodology termed by the ESRC as “thick description” (Jewitt 2012)(p6).

3) its durability, malleable, and share-ability

The ESRC extol video as “a sharable, malleable digital record” (Jewitt 2012)(p2). Video data can be viewed in slow or fast motion, freeze-frame, with or without sound or image. These capacities enable different levels of analytical gaze (micro to macro) and maximise analytical distance and reflexivity (Lemke, 2009, as cited in Jewitt 2012). An example of this was given by [9]. Here, the video tapes were played back at accelerated speed. Thus, an 8 h night's sleep was replayed in 45-60 min. “In this speeded-up mode, the phasic activities of sleep -especially the REMs, body movements, and facial grimaces-are greatly exaggerated” (p10). In [36] segments of the videotapes were viewed multiple times in order to clearly determine the exact nature of each behaviour.

Video data can be stored as digital, portable files and backed up on external hard drives (as cited in [11]). Being a shareable medium, video data can support collaborative analysis between researchers and to invite scrutiny and discussion (Lapadat 2000, Harris 2016). In this vein, four studies ([9], [17], [19], [31]) used a previously validated coding scheme and five studies incorporated inter-rater reliability ([9], [11], [17], [35], [36]) [35] was the only study to offer participants the opportunity to view their video-tapes and even gave each participant a tape of clips from their 2 nights of filming.

This virtue of video necessitates several important considerations. As a shareable, multi-modal medium, video requires sensitive consent protocols for the use of the data (e.g., research or publication). Further, as a malleable medium, it is at risk of technical corruption and subject to time (gigabit) limits. In [16] for example, no coding was given in case of technical problems and due to delay in the introduction of a new cassette in the recorder. In [17], for six of the eighty-eight infants enrolled in the study, the equipment failed or data were insufficient. [36] experienced several technical issues that interrupted all or some of the audio capture and one participant was excluded from analysis because of recording failure. Further in that study, one participant discontinued participation because mechanical problems with one of the overhead cameras caused too much noise for the participant to sleep.

ESRC validity guidelines

According to ESRC guidance (Jewitt 2012), the validity of video methodology in social science can be formally critiqued through two aspects:

1. Ecological validity (camera-in-situ- effect)

Methodological discourse has long recommended that researchers are mindful of the ecological validity of their data collection instruments (Lewkowicz 2001, Schmuckler 2001, Sánchez-Ortuño, Edinger et al. 2010). The ESRC recognises that the video recording technology 'participates' in the production of the data (Jewitt 2012). The present review found no attempt in any social science study to minimise the presence of the camera by, for instance, the use of small wall or ceiling mounted cameras or the use of one-way mirrors. This is problematic, particularly for studies including adult behaviour in their analyses, such as the bedsharing study [25] and those exploring parental responsiveness ([9], [16], [17]). Further, the presence of connecting cables can be both obtrusive and hazardous. In one home study ([9]), a 20 foot cable connected the camera to the recorder. Similarly, in another home study ([11]) cameras were connected to the recorder via cables secured to the floor. Modern studies could mitigate such obtrusiveness via wireless technology, although this approach was absent across all studies in this review.

2. The 'reality status'

Most studies in the field of infant sleep have used parental reports rather than video. Whilst parental reports can assess the impact of infant signaling on parents, it cannot accurately capture the 'reality status' of infant behaviour because parents are often unaware of infant waking that does not include signaling ([31]). As a data collection instrument, video data capitalizes on infants' available response repertoire, capturing a wide range of naturalistic behaviour. In this sense, video data can boost the internal and ecological validity of research (Lewkowicz 2001). Illustrating this concept, video was essential in [17] which sought to describe the development of infant self-regulating behaviours in response to middle of the night awakenings. Similarly, [9] was the first longitudinal study of infant object use at night. The researchers assessed whether introducing a sleep aid infused with maternal scent at different ages would impact infants' self-soothing. It was one of the first studies to use "objective means" of determining sleep aid use (Burnham, Goodlin-Jones et al. 2002)(p10). Likewise, [11], [18] and [31] used video to assess the accuracy of parental report. In each study, parental report significantly overestimated sleep period duration and underestimated the number of night waking episodes, compared with video.

In recording the reality status of a phenomena, the ESRC assert that a key advantage of video in social science is it can support an *exploratory* research design (Jewitt 2012). Video can remain 'open' for longer than other data collection methodologies because data management and coding (i.e., 'focusing down the data') is usually employed at a later stage. Interestingly, none of the social science studies in this review were inductive in design. Researchers in one home study [31] for instance, asked participants to follow their usual night-time habits but used a pre-defined taxonomy for coding.

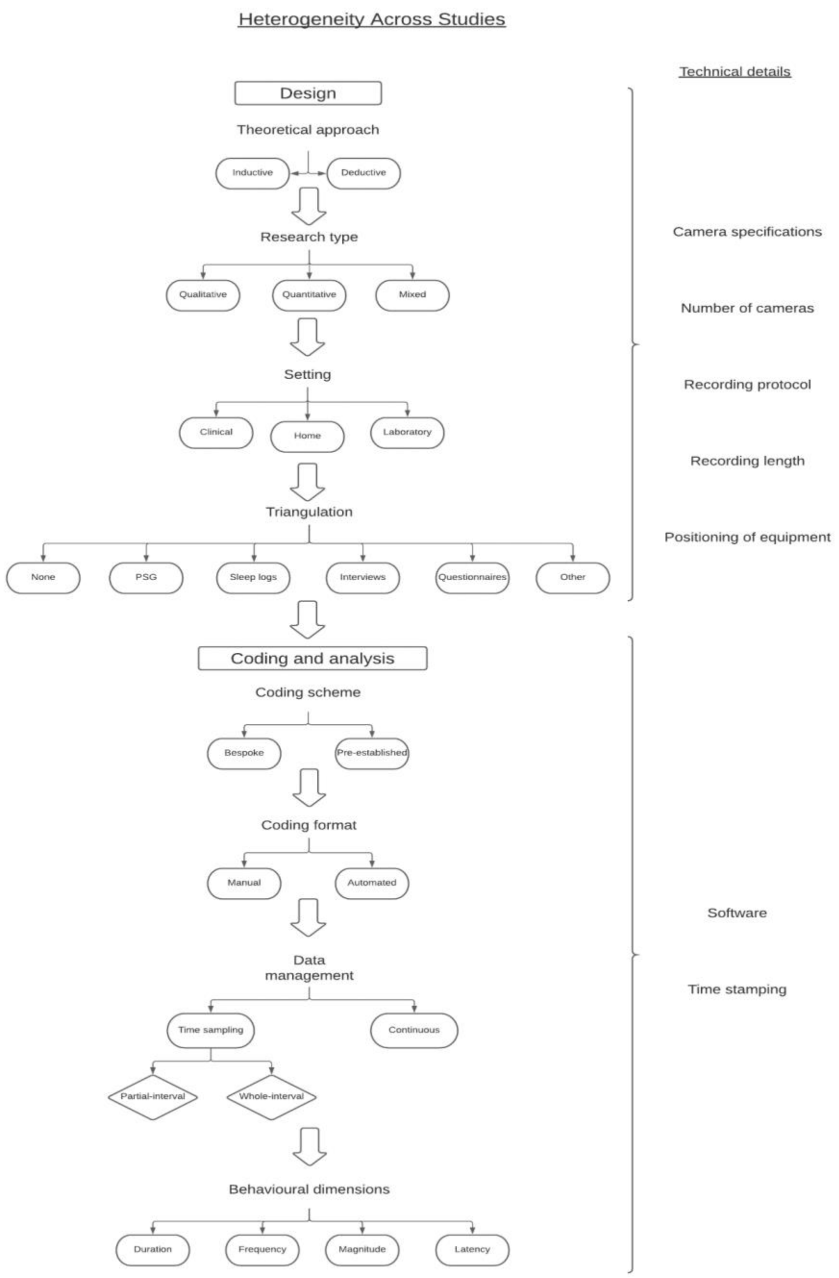
Assessing The Robustness of the Synthesis

The robustness of the review synthesis will now be assessed using the subheadings recommended by Cochrane (Ryan 2013).

Overall completeness and applicability of evidence

In addressing review Question 1 'How do video-studies of infant sleep differ?', the broad inclusion criteria captured a comprehensive range of differences across studies at each core methodological stage. To reduce risk of bias towards experimental studies, the inclusion criteria specified that video could be used as a primary or secondary data collection tool. Moreover, 'infant' included all children < 1 year rather than simply newborns, and premature infants were included. 'Sleep' was similarly broadly interpreted to capture all enquiries, whether psychological, behavioural or medical. All disciplines and all settings were included.

Figure 27 Diagram showing heterogeneous aspects across studies



Nonetheless, this review does not provide information on the use of video in qualitative research, aside from its contribution in mixed studies (those with both quantitative and qualitative components). This finding was surprising given that video enables detailed scrutiny of behaviours as they arise, providing the opportunity to capture the multimodal qualities of infant sleep, factors considered "the staples of any qualitative study" (Ratcliff 2003)(p113).

Quality of the evidence

In addressing review Question 2 'How Robust is Videosomnography for Assessing Infant Sleep?' a critical appraisal of each study was performed. A major facet of the appraisal process involved screening each study through the Cochrane 'Risk of bias' assessment standards (Higgins, Thomas et al. 2019). Following this process, the studies were categorised as either high risk of bias (n=9 studies), moderate risk of bias (n=13 studies) or low risk of bias (n=9 studies). Five studies did not provide enough details for an accurate assessment. Of those studies categorised as high risk of bias, 55% were conducted in clinical settings and 44% were evaluation studies. In contrast, of those studies categorised as low risk of bias, only 33% were conducted in clinical settings and only 11% were evaluation studies. Further, 0% of low risk studies used PSG to code sleep states in contrast to 33% of studies with high risk of bias. These findings indicate that robustness in the study of infant sleep is currently associated with naturalistic environments and against reliance on PSG and novel methodological approaches such as automation.

The outcome of the video element of the methodology was unclear in 15% of studies. This indicates that video may have been used because it was available and traditional rather than appropriate to the research aims. Further, the exclusion of video data in the reported findings could have been influenced by the results, potentially making the findings of these studies misleading (Higgins, Thomas et al. 2019).

In summary, a relatively small proportion of studies were at low risk of bias (25%). This suggests that enquiries of infant sleep are challenging to align with positivistic standards of robustness.

Potential biases in the review process

Systematic reviews are typically conducted by teams of researchers (Uttley and Montgomery 2017, Hong, Fàbregues et al. 2018, Lasserson, Thomas et al. 2019). As much of systematic reviewing is about judgment making, conducting this review as a lone researcher is a significant limitation increasing risk of researcher bias.

In lieu of universal standards in the conduct, analysis and presentation of methodological reviews, this systematic review integrated the features of several existing review instruments. These included the Cochrane assessment standards (Higgins, Thomas et al. 2019), guidelines of the Joanna Briggs Institute (National Childbirth Trust 2015), ESRC validity guidelines (Jewitt 2012), and the Mixed Methods Appraisal Tool (MMAT) (Pace, Pluye et al. 2012). These instruments were not designed to assist methodological reviews and their employment may have biased this review towards a medical ontology.

Regarding the review design and search process, the term 'location bias' refers to the accessibility of studies based on variable indexing in electronic databases (Higgins, Thomas et al. 2019). To mitigate the risk of this bias, hand-searching of eight major journals was performed. As handsearching requires a basic knowledge of study design methods and terminology, the process did not include journals outside the author's area of expertise and only English language studies were included.

Nonetheless, the inclusion of extensive hand-searching and grey literature databases strengthens the likelihood that all relevant studies were identified. In Cochrane terms, 27% of included studies in this review were composed of negative or 'non-significant' results (Ryan 2013)[14]. This finding provides some evidence against reporting biases such as publication bias (Higgins, Thomas et al. 2019).

When grouping studies by phenomenon of interest, two studies ([7], [8]) were difficult to categorise as their topic (environmental SIDS risk factors) did not fit easily into one of the predetermined outcome categories. The decision to include them within the 'sleep interventions' category was based on the similarity of their results with the other studies in that group. Consequently, that category was broadened theoretically. Thus, an inclusive approach was prioritised over specificity in this instance. Similarly, an inclusive approach informed the generous interpretation of 'infant', which included premature infants and those with medical pathologies. Moreover, studies were included that featured infants >1 year if the sample also featured the target age range. These factors may influence the generalisability of the synthesis.

Recommendations and conclusion

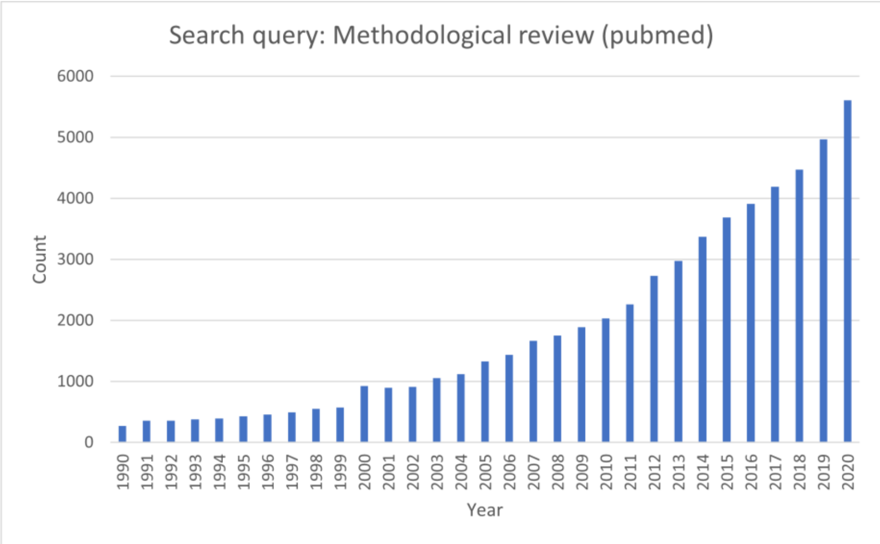
Over two decades ago it was claimed that "visual inquiry has for the most part failed to connect with the wider currents in social theory" (Emmison and Smith, 2000, as cited in Pink 2001)(p587). The findings of this review indicate this critique retains weight today. Ideas and theories generated in the field of infant sleep research are directly related to the research methodologies. Despite different epistemological bases, the abundance of quantitative research, prevalence of deductive epistemology and absence of qualitative research suggests that positivist and scientific ontologies dominate the field of infant sleep research. To the best of my knowledge, this work is the first attempt at a comprehensive systemization on this topic. Wider insight may be gained by filtering the studies through other epistemological approaches, such as objectivism, constructionism or subjectivism. Relatedly, the review strengthens the conclusion of previous scholars, that the development of consensus-based guidelines for methodological reviews is warranted (Lawson, Colunga Lozano et al. 2019).

A standardised checklist for video studies

Methodological reviews are regarded as highly informative because they allow researchers to generate empirical evidence on the quality, completeness and accuracy of reporting; document the variety of methods used; investigate adherence to guidelines; assess approaches to analyses; and demonstrate changes in epistemology over time (Lawson, Leenus et al. 2020). A Pubmed search (Figure 29) illustrates the rapidly growing popularity of this field.

[14] Outcomes for each study are collated in Appendix [insert number].

Figure 28 Search results for 'methodological review' (1990-2020) Pubmed, conducted 28/08/2021



Unfortunately, this review has revealed wide inconsistencies in video research nomenclature and reporting practices. As discussed, these factors complicate the 'systematic' element of the systematic review process. The field of video research would therefore benefit from an efficient way of reporting research methods and summarising methodological issues. To assist future reviewers, I have created a standardised checklist for video studies. Using the acronym C.A.M.E.R.A, the aim of this reporting tool is to regulate the nomenclature and reporting of video studies to ensure a standardized and transparent approach to reporting is followed.

Figure 29 CAMERA: a standardised checklist for reporting video studies

CAMERA	
Model	
Digital vs. Film	
Monochrome vs. Colour	

Illumination (e.g., integrated infra-red, external light source)	
Lens	
Audio (e.g., integrated microphone, external microphone)	
Resolution (pixels)	
Frame rate	
Shutter Speed	
Sensitivity (lux)	
Modifications (e.g., HD, anti-Blooming, dome, gain control)	
AIM	
Aim of study	
Epistemological stance (inductive/deductive)	
Sample	
Participant characteristics	
Macro setting (e.g., country, culture)	
Micro setting (e.g., lab, clinic, home)	
Outcome variables	
Funding	
Discipline (e.g., Medicine, Anthropology)	
METHODOLOGY	
Approach (qualitative/quantitative/mixed)	
Supplementary methods (e.g., polysomnography, interview, sleep log)	

Sampling design (e.g., cross-sectional, case study, RCT)	
Specific research components (e.g., experimental/non-experimental, randomized/non-randomized)	
Legal and ethical issues	
EQUIPMENT	
Number of cameras	
Camera mounting (e.g., tripod, ceiling)	
Camera positioning (e.g., location, metres from subject)	
Camera mobility (e.g., panning, zooming)	
Connectivity (e.g., feeds into recording device / transmitter / computer)	
Other equipment	
RECORDING	
Recording protocol (e.g., start & finish procedures)	
Adaption period	
Camera operator (e.g., participant/researcher/motion-activated)	
Recording length	
Data storage	
ANALYSIS	
Analytic plan	

Epoch length	
Variables chosen (duration / frequency / magnitude / latency) including categories within each variable	
Validated coding scheme	
Coding software (e.g., Noldus Observer, Bosch Divar, custom developed)	
Statistical software (e.g., SPSS, R)	
Blind coders	
Inter-rater reliability	
Automation	
Attrition	
Technical effect (e.g. limitations of camera lens producing a truncated view)	

To my knowledge, this is the first tool of its kind for video observation studies. My tool ensures the reporting of specific methodological components are clearly articulated and defined, in enough detail, to allow reviewers to perform adequate appraisal and synthesis within and between reviews. If studies are not reported in a transparent manner, it is impossible for reviewers to verify how rigorously they were conducted or whether important evidence was missed, and overall, reduces the reliability and usability of a synthesis (Dodgson 2021).

Video research has much to offer methodological reviewers. The present review has demonstrated the strength of video's flexibility across wide-ranging disciplines. The different uses of video have been mapped and key qualities and constraints of the methodology have been outlined. The review has highlighted the importance of research setting in considerations of robustness. When assessing infant sleep, video is highly robust within home settings, which thus serve as the ideal environment for such research. Moreover, video is robust relative to other methods of scoring infant sleep such as PSG, sleep diaries and interviews, although those tools function as useful complimentary methods for triangulation.

Even though video is a significant resource for infant sleep researchers, its use necessarily involves 'trade-offs'. Instrumental choices include where to place the video camera, whether to have a fixed or mobile camera, where to focus the camera, how long to record for and when to record. Decisions of camera type, positioning and operator shape all data collected. Each commitment is associated with consequent gains and losses. For instance, current automation technology strengthens efficiency at the expense of accuracy. More generally, this review underpins that all methodological choices should be informed by the outcome phenomenon of interest. In reference back to the review's hypothesis, video methodology can either increase or decrease risk of bias depending on the manner of its incorporation and its appropriateness to the study aims.

Chapter 7. Swaddling: a sleep study

Introduction and Rationale

As detailed in the literature review, despite a swaddling renaissance in contemporary western culture, knowledge of the physiological and social mechanisms involved in the practice is unclear. Available data are inconsistent and fail to ascertain feeding method or to distinguish between infants naive to the intervention and those routinely swaddled. As recently as 2015, authors have criticised the majority of infant crying and sleeping studies for relying upon parental reports (St James-Roberts, Roberts et al. 2015). Whilst that methodology is necessary to assess the impact of infant signalling on parents, it does not provide a clear picture of infant behaviour as parents are often unaware of infant waking that does not include signalling (Anders and Keener 1985). This sleep laboratory crossover study examined the impact of swaddling upon infant sleep outcomes in healthy term breastfed infants under 4 months of age.

This project addresses knowledge deficits identified in Chapter 4 (biobehavioural review) through a PICO approach to evidence-based practice (Richardson, Wilson et al. 1995, Huang, Lin et al. 2006). Infants less than 4 months of age comprised the **Population** to which the **Intervention** of swaddling and **Comparison** of non-swaddling was applied. Effects on sleep states, for instance the number of sleep states experienced during the coding epoch, feeding, and maternal interaction, were recorded and analysed as **Outcomes**. The study uses objective video methodology validated for the purpose of measuring infant behaviours discussed in Chapter 6 (systematic review of video observations of infant sleep) (Anders and Keener 1985, Goodlin-Jones, Burnham et al. 2001, Sitnick, Goodlin-Jones et al. 2008).

Ethics Approval

Ethical approval was obtained from the Durham University Department of Anthropology Ethics and Data Protection Subcommittee on 11th Feb 2016. Informed parental consent was obtained before the study.

Hypotheses

Hypothesis 1: Swaddling affects feed frequency and duration in breastfed infants.

To date, only one swaddle study has indicated infant feeding method. Richardson and colleagues identified that the infants in their study were breastfed but did not determine whether they were exclusively breastfed or breastfed in conjunction with formula feeding and/or solid food (Richardson, Walker et al. 2010). Furthermore, they did not explore how swaddling impacted upon feeding. Whether an infant is exclusively breastfed, exclusively formula fed, or a combination of both methods, may be a modifying variable in the context of swaddling. Based on the findings of Chapter 4 (biobehavioural review), it is predicted that exclusively breast-fed infants will exhibit a reduction in feed frequency and duration when swaddled.

Hypothesis 2: Swaddling affects sleep states in breastfed infants.

This hypothesis was informed by the suggestion that "external conditions have a modulating effect" upon the regulation of sleep cycles (Prechtl 1977)(p210). Not only is swaddling a relevant external condition, method of infant feeding may also be critical. For instance, formula-feeding and swaddling have respectively been shown to increase duration of active sleep (Harper, Hoppenbrouwers et al. 1976, Butte, Jensen et al. 1992, Franco, Seret et al. 2005). This data suggests that the physiological effects of formula feeding on infant sleep share similar characteristics to those observed through swaddling. It is, however, unclear whether and to what extent these changes affect breastfed infants. It is predicted that the breast-fed infants in the present study will experience a longer duration of time spent in active sleep when swaddled than when unswaddled.

Hypothesis 3: Swaddling affects the form and frequency of mother/infant interaction.

There are no known studies investigating the interaction between swaddling and maternal-infant interaction. Given that mothers interpret and decode their infant's capacities and needs through their motor cues (Trevarthen 2011, Feldman 2012), it is predicted that swaddling will reduce the frequency of mother-infant interaction overall and may affect the form of such interaction, for instance reducing touch-based interactions and/or increasing vocal-based interactions. This in turn may interact with changes in other dependent variables (thus impacting hypotheses 1 and 2). For instance, if the infant is frequently aroused by the mother, the infant may experience less quiet sleep and so ostensibly demonstrate more periods of active sleep since infants' transition into active sleep first.

Hypothesis 4: Swaddling produces a cumulative reduction in arousal.

Based on the findings of previous studies (Manaseki-Holland, Spier et al. 2010, Richardson, Walker et al. 2010, Dixley 2015), it is anticipated that infants in the present study will spend more time asleep while swaddled. During awake periods, the motor restraint will mean that swaddled infants will spend more time in a quiet awake state than an active awake state whereas the reverse will be true for unswaddled infants.

Hypothesis 5: Swaddling discourages face-to-face sleeping orientation in mothers and infants.

There are no known studies investigating the interaction between swaddling and maternal-infant sleep orientation. As swaddling may reduce interaction between mother and infant, and therefore reduce sensory exchanges (Hypothesis 3), it is predicted that this will be reflected in the sleep facial orientation of the dyad. This hypothesis builds upon the assumption, outlined in the literature review, that swaddling acts as a barrier between the dyad (Bacon, Bell et al. 1991, Cheng and Partridge 1993, Ball, Ward-Platt et al. 2006, van Sleuwen, L'Hoir M et al. 2006). When swaddled, it is anticipated that infants will spend more time with their faces orientated to each side for equal proportions of the night (behaviours characteristic of solitary sleeping, (Richard, Mosko et al. 1996)); however, when unswaddled, it is anticipated that infants will demonstrate a preference for facing the mother. These observations are expected notwithstanding that breastfeeding has been shown to promote face-to-face sleep orientation (Ball and Klingaman 2008).

Experimental design and methods

Recruitment

The project used social media as a key recruitment tool to access potential participants. Online recruitment is associated with lower costs (Christensen, Ekholm et al. 2014, Lane, Armin et al. 2015, Christensen, Riis et al. 2017, Harris, Anzman-Frasca et al. 2020) and higher recruitment rates (Wise, Rothman et al. 2015, Christensen, Riis et al. 2017) compared to traditional recruitment methods. The Facebook platform was selected on the grounds that it is convenient, free to use, has an interface that encourages snowball 'sharing' of content, and crucially, is best fitted to recruiting the target population - women of childbearing age (UMPF 2020). The recruitment strategy involved placing engaging poster-style adverts on Facebook groups that had a breastfeeding target demographic and were situated in the North East of England, where this project was undertaken. According to a UK Government research, the most common reason for using social media is "to find out what's happening in the local area" (UK Department for Culture Media and Sport 2016) (p4).

A 2016 review exploring the use of social media as a recruitment strategy for health research found that using a combination of social media websites, or *not* using Facebook, resulted in lower recruitment (Topolovec-Vranic and Natarajan 2016). Facebook is the most popular social media platform in the UK (Alphabeta 2019). 80% of UK females have an 'active' Facebook account. Large-scale data suggests that Facebook is 'frequently' used by 95% of 18-24 year olds, 88% of 25-34 year olds, 80% of 35-44 year olds and 71% of 45-54 year olds (Alphabeta 2019). Furthermore, data has shown no evidence of ethnicity-bias on this platform. Of UK social media users, distributions of ethnicity reflect distributions in the general population. For instance, 12.6% of Facebook users are non-white aligning with 13.0% of the adult population that are non-white (UK Department for Culture Media and Sport 2016).

An online 'registration of interest' form (Appendix 3) was created using JISC Online Surveys, the recommended survey platform for use by staff and students at Durham University. The form ensured that mothers received information about the purpose of the study and the nature of their participation, but were blind to the specific hypotheses being tested. In this respect, it served as a screening measure to ensure the inclusion and exclusion criteria were met prior to enrolment.

Inclusion criteria

Inclusion criteria were as follows: 1) Maternal participants have adequate comprehension of verbal and written English. 2) Infant participants have no previous experience of swaddling. This will avoid sensitisation to the intervention, a phenomenon evident in two swaddling systematic reviews (van Sleuwen, Engelberts et al. 2007, Dixley 2015). 3) Participants are engaged in exclusive breastfeeding at the time of recruitment and throughout the study.

Exclusive breastfeeding was defined as per the World Health Organization definition: no other food or drink except breast milk (including milk expressed or from a wet nurse), but allowing the infant to receive ORS, drops and syrups (vitamins, minerals and medicines).

Exclusion criteria

Inclusion criteria were as follows: a) Participants have any of the SIDS risk factors: prone sleeping, maternal smoking, maternal alcohol consumption, prematurity and recent infection; these factors can depress "arousability" (Horne, Parslow et al. 2004)(p24) and arousability is linked to a key variable in the present study - sleep state (it is thought easier to arouse from active sleep). b) Participant infants that regularly used dummies/pacifiers; these have been shown to affect feed frequency and increase arousability (Horne, Parslow et al. 2004). c) Routine bed-sharing participants - any infant that habitually sleeps in the same bed as its primary carer. Such infants are naïve to cot/bassinet sleeping and therefore, if permitted into the study, would have been subjected to this as an additional novel intervention above and beyond swaddling, risking confounding.

Withdrawal criteria

Participants were informed they may stop participating in the study at any time. Mother-infant dyads were to be administratively withdrawn if they met one or more exclusion criterion that had not been previously disclosed.

Study Environment

Studies from a 2015 swaddling systematic review (Dixley 2015) that found the intervention to produce measurable outcomes (Richardson, Walker et al. 2010, Meyer and Erler 2011) were conducted in sleep labs. The remaining studies, each of which failed to ascertain measurable outcomes, were run in home settings. By conducting the present project in a lab, the same standardised environment in as closed a system as possible was provided for each subject. This is thought to strengthen internal validity over a home setting, as the latter comprises open and complex systems (Greener 2011).

To enhance the ecological validity of the project, the lab was equipped to resemble a typical Western home environment with private bathroom, kitchenette, sofa, a king-size bed and bassinet (see Figure 31). Facilities were available if mothers wished to bathe their baby, watch TV or make refreshments as per the sleep routine that was typical for them. The ambient temperature of the lab was standardised between 16-20°C as recommended by SIDS prevention guidelines (The Lullaby Trust 2019). This variable is important as changes in environmental temperature have been shown to significantly modify an infant's cardiorespiratory and autonomic parameters (Franco, Scaillet et al. 2004).

Finally, because infant sleep proximity to the mother has been shown to influence the frequency and duration of feeding bouts (McKenna, Mosko et al. 1997), this proximity was kept uniform for each subject. Mothers were required to sleep in the same room as the infant and infants were required to sleep in a bassinet adjacent to the maternal bedside (Ball 2017).

Figure 30 Durham University Infancy and Sleep Centre

Enrolment

Voluntary informed consent was obtained before enrolment in the study in accordance with the 'Declaration of Helsinki', a set of ethical principles providing guidance to participants in medical research involving human subjects, developed by the World Medical Association (WMA 2013). Potential participants were provided with an information sheet and consent form and invited to visit the Sleep Lab prior to giving their final consent. The enrolment form (Appendix 4) included questions pertaining to infant age, maternal age, maternal smoking status and maternal alcohol consumption. Hollingshead indexes of marital status, maternal education, family income and ethnicity were used as measurements of socioeconomic status (Hollingshead 1975). These data were collected in order to characterise the participant sample.

Study design

This study employed a randomised cross-over design where the subjects served as their own controls so that the same individual was tested under both experimental (swaddled) and control (non-swaddled) conditions on separate nights. The nights were consecutive, therefore minimising the impact of any within-infant developmental changes. To delimit the degree to which data might be confounded by the residual effects of laboratory adaptation, reduce carryover effect and rule out allocation bias, participants' starting conditions were randomised on the first night using coin toss. Previous swaddling studies have tended to focus on daytime 'naps' due to the logistical challenges inherent in overnight monitoring (Gerard, Harris et al. 2002, Richardson, Walker et al. 2009, Richardson, Walker et al. 2010). In contrast, the present study used lab facilities to monitor sleep overnight while participants followed their normal sleep practices.

Swaddle selection and procedure

Swaddles can take different forms. For instance, fastenings may include poppers, zips and Velcro, whereas material can range from cotton to bamboo. To ascertain the most appropriate swaddle product for the study a selection of swaddles were examined with infants sharing the same demographics as the sample population to ascertain the effectiveness of each swaddle in accommodating the monitoring equipment, the ease of nappy changes, tightness of motor restraint, and infant comfort. In accordance with the Uniform Requirements for Biomedical Writing (Kazakovceva 2016), swaddle products were purchased from retail outlets and there was no conflict of interest from swaddle manufacturers or any other agencies.

Regarding swaddle technique, the traditional use of a blanket bears the risk of infants breaking free and suffocating in the resulting free blanket. Mindful of this, the study used a zip-up swaddle pod that allowed for hip flexion and abduction, chest excursion and robust confinement. This swaddle device was similar to that adopted by Gerard and colleagues in their study of arousal (Gerard, Harris et al. 2002), but with important differences (Figure 32). Like Gerard's swaddle, the study swaddle had a central zipper to facilitate adjustment of the sensors and nappy changes. It also allowed hip flexion/abduction and chest wall excursion and prevented infants from breaking free of the swaddle. However, unlike Gerard's swaddle which restrained the infant's arms at the side with internal restraints, the present study protocol involved placing the infant's arms across the chest prior to zipping the swaddle, as per recommended guidelines (The Lullaby Trust 2020). This allowed the infant to move their arms within the constraints of the swaddle material.

Figure 31 left: gerard et al 2002; right: present project 2020.

The infants' legs were placed in the 'frog position', a practice recommended by the National Childbirth Trust (National Childbirth Trust 2015) to protect from hip dysplasia, and the infants were clothed in nappy, vest and sleepsuit, an approach endorsed by SIDS guidelines (National

SIDS Council 2009) and the infant was placed supine in the bassinet following SIDS prevention protocol (BASIS 2018, The Lullaby Trust 2019).

Mothers were blind to the specific hypotheses being tested and informed that the effects of swaddling on infant sleep were being assessed. Mothers performed all caretaking interventions themselves. Mothers retired at their usual times, and monitoring was terminated after mother and infant had awakened the next morning at their usual times, per established laboratory protocol in infant sleep research (McKenna, Mosko et al. 1997). As the swaddle pod enabled nappy changes without necessitating removal of the swaddle, the infant was not unswaddled at any point on the designated night. This included during feeding episodes, as per maternal decision.

Data Collection

To reduce risk of confounding, the infants were placed to sleep in the same position, under the same conditions (e.g. after a feed), in the same location. Infants wore the same amount of clothing and were covered with the same thin cotton blanket for sleep when unswaddled. The same researcher applied the swaddle and physiology equipment to each infant.

The choice of data collection methodology was informed by the research aims, the resources available at the lab, and time available for the study. The researcher was fortunate enough to have access to both observational (video) and physiological channels of data collection that allowed estimation of infant sleep state at any given moment. Recording began when the infant was placed in the bassinet and ended upon both infant and mother awakening after 6am.

Infra-Red Video

The study utilised direct behavioural observation as the core method of identifying infant sleep states and of identifying feeding frequency and duration, believed to be the most reliable and efficient approach for young infants (see systematic review, Chapter 6). Video recordings were made from three ceiling-mounted infra-red cameras positioned to capture images of the bed and bassinet. The video signal was transmitted to the adjacent monitoring room where it was continuously recorded using Noldus Observer software. Each camera could be panned and zoomed remotely from the monitoring room.

Paediatric Respiratory Plethysmography Band

Supplementary to behavioural observation, respiratory variation is regarded as the most useful physiological characteristic for staging sleep in young infants (Grigg-Damberger, Gozal et al. 2007). Irregular respiration is associated with active sleep and regular respiration with quiet sleep (Wolff 1959, Parmelee, Akiyama et al. 1969, Kirjavainen, Cooper et al. 1996). The regularity or irregularity of respiration was captured using a paediatric respiratory plethysmography band placed under the swaddle. This data collection device has been used successfully in previous swaddling studies (Gerard, Harris et al. 2002). The signal was transmitted to the adjacent monitoring room where it was continuously recorded using Aqcknowledge software, BIOPAC Systems Inc.

Pulse Oximeter

An acceleration in heart rate has also been associated with active sleep (Villa, Calcagnini et al. 2000). This shift begins several minutes before and after the active sleep epoch (Shott 1996). In the present study, heart rate was captured using a wrap-around pulse oximeter (recording both oxygen saturation and pulse rate) positioned on the infant's foot. The signal was continuously recorded using Aqcknowledge software, BIOPAC Systems Inc.

Experiment protocol

After arriving at the lab (6-7pm), mothers and their infants were greeted by the principal investigator (PI) and given a tour of the lab and its facilities. The mother was then instructed to make themselves comfortable and engage in their normal evening routine. During this time, the PI readied the software in the monitoring room. When the mother signalled that she and her infant were ready to sleep, the PI attached the sensors to the infant and swaddled the infant (if appropriate night). Mothers were instructed to alert the PI if there were any technical or other issues through the night. The PI then retired to the monitoring room for the night. In the morning, once both mother and infant were awake and active, the PI ended the recording and removed the sensors.

Data management and analyses

Coding protocol

Adopting an ethological approach, the project used focal sampling to code the behaviour of the mother-infant dyad over a predetermined period of time. Mirroring the protocol of a previous study of infant sleep cycles conducted at the same lab (Leech 2006), of prior research conducted by the thesis supervisor (Ball, Ward-Platt et al. 2006), and according to recommended practice (Elder 1999, Kopenhaver Haidet, Tate et al. 2009), a four hour period was coded from each observation. This period comprised of two hours taken each side of the median point of the entire observation (Leech 2006). The data analysed thus reflect the relative (rather than absolute) difference between the groups, an approach also adopted in previous swaddle research (Franco, Seret et al. 2005). Four hours has been considered long enough for infants to potentially experience at least two full sleep cycles whilst also reducing the effect of erratic data at the beginning and end of the night caused by the process of going to bed and getting-up (Franco, Seret et al. 2005), a phenomenon known as the "first-nap effect" (Bernstein, Emde et al. 1973).

This study utilised direct behavioural observation as the core method of identifying sleep and awake states and, using a split-screen monitor, coded this alongside physiological data. Although this approach is believed to be the most reliable and efficient (Bertelle, Sevestre et al. 2007), its application is currently characterised by a lack of universal coding criteria. After a thorough review of the literature, a coding taxonomy was developed using distinct groups of behavioural and physiological markers. Many of these markers and their distinguishing features were taken from previous work targeting young infants (Thoman 2001). Before coding proper, the taxonomy was tested for appropriateness on a handful of 4-hour epochs.

Each video recording was coded at normal speed except during periods of high activity, when recordings were paused, rewound and re-watched where necessary. Movement artefact and periods where sensors dislodged were excluded from the physiological record, as per standard practice in such studies (Ball 2009). Where relevant to the hypotheses, duration of behaviour was coded in addition to frequency. Coding was conducted entirely by the principal investigator who was not blind to the hypotheses. Due to time and resource constraints coding was not independently validated. In cases of equipment failure, epochs were coded as missing data.

Coding taxonomy

A behavioural coding taxonomy was created to facilitate observational analysis (Table 11). Sleep-awake states have traditionally been used to understand the integrity of the infant neurobehavioural system and to examine that system's regulatory controls (Thoman 2001). One reason for discrepancies in findings between sleep studies is that typically state behaviours must endure for an arbitrary period before they can be scored, and the parameters of this duration vary between studies. To capture the majority of states whilst ensuring validity, the present study adopted a 30 second criterion. Thus, for a state to be coded, it must endure for at least thirty seconds. This period is thought optimal for studies of infant sleep and arousal (Guilleminault and Souquet 1979, Mosko, McKenna et al. 1993, Salzarulo.P 2002). Crucial for present purposes, it is believed appropriate for infants younger than four months of age given their newly developing central nervous systems and related incapacity to sustain states for prolonged periods (Giganti, Fagioli et al. 2001).

Table 11 Coding Taxonomy

Category	Variable	Frequency/ Duration	Behavioural observations (necessary)	Behavioural observations (supplementary)
Infant sleep	Active awake.	F&D	>30 seconds. Eyes are open. Motor activity and/or vocalisations.	May correspond with crying or fussing.
	Quiet awake	F&D	>30 seconds. Eyes are open. Motor activity is low. No vocalisations.	
	Quiet sleep.	F&D	>30seconds. Eyes are closed. Respiration is relatively slow, regular and abdominal in nature. A tonic level of motor tone is maintained,	Brief periods of limb or body movements. Sighing or rhythmic mouthing.

			and motor activity is limited to occasional startles.	
	Active Sleep.	F&D	>30 seconds. Eyes are closed. Uneven respiration that is primarily costal.	Intermittent rapid eye movements. Sporadic body movements. Smiles, frowns, grimaces, mouthing, sucking, or sighing.
	Indeterminate sleep.	F&D	>30 seconds. Mixed behavioural signs of active sleep and quiet sleep. Respiration not as regular as quiet sleep.	Twitching or trembling movements of the extremities.
Feeding	Breastfeeding.	F&D	Infant has latched onto breast for > 30 seconds. Feeding ends at the moment infant unlatches from breast if then remains unlatched for > 5 minutes.	
Interaction - Mother	Touching.	F	A part of the mother's body meets the infant.	
	Moving.	F	Mother moves location of infant.	
	Mother vocalisations.	F	Mother makes audible utterance. (Researcher not present).	
Interaction – Infant	Fuss	F&D	Sounds made continuously or intermittently, at relatively low levels of intensity, that signal discomfort. Does not include the open mouth of a 'cry face' or full body tension.	
			Mouth stretched open. Brow wrinkled. Intense vocalizations occurring singly	

	Cry	F&D	or in succession, that signal discomfort.	Legs and arms flail.
	Rooting	F	Infant opens mouth, either widely for two seconds or in quick small puckering movements (open-close-open-close) / Infant puts fingers or fist into mouth.	Sucking motions with the mouth. Moving of the head back and forth. Lips thrust forward. Tongue moving.

As infants do not show the adult structure of sleep (Curzi-Dascalova, Bloch et al. 2000, Holditch-Davis, Blackburn et al. 2003, Graven 2006), the taxonomy adopted the sleep states of active and quiet sleep, rather than REM and NREM (non-REM) sleep. Sleep states were distinguished by triangulating observational with physiological data via Noldus Observer in conjunction with Acqknowledge. Thus, a correspondence of respiration, heart rate and visual data were required for a state to be scored (Wolff 1966, Parmelee and Stern 1972). Awake states required opening of the eyes, a criterion used in previous research (Kahn, Rebuffat et al. 1992). These rules do not discard any coded behaviours. They assign the behaviours to one or the other categories, so that measures can be made of the amounts of time spent in each behaviour state including overlapping behaviours. Epochs that did not fulfil the taxonomy for either sleep or awake states, perhaps because the infant was exhibiting a mixture of behaviours, were coded as indeterminate.

Data management

This section details how the enrolment forms, video files, physiological files, and outcome variables were processed for the analyses presented in the results section.

Data was coded within Noldus Observer. Per night of observation, Noldus Observer and Aqknowledge software each generated one output file. For each night, the corresponding output file from Aqknowledge was imported into Noldus Observer and synchronised for split-screen coding. When coding was complete, the new output file was exported to Statistical Package for the Social Sciences version 24 (SPSS Inc., Chicago, IL, USA).

Confidentiality of personal data was ensured through the immediate assignment of anonymous participant codes. Thereafter, anonymity was protected by ensuring names or identifiable information are not linked to the data and all paperwork linking names to participant codes was stored in locked file cabinets in the secure Infant Sleep Centre in accordance with the Data Protection Act, the General Data Protection Regulation 2018, and the Caldicott principles of information governance. Video data was stored on an encrypted university computer or designated encrypted laptop with firewall protection. Electronic data whether text or video-based were protected using a strong password, changed regularly. Electronic data was stored on designated drives and servers, and backed up and reviewed frequently. Access to the data was restricted to researchers at Infant Sleep Centre and only when required for research work. After 2023, electronic data is to be deleted. Paper-based data will be shredded and disposed of securely.

When working with personal data, researchers ensured the screens of their computers and/or laptops were always locked when unattended. Personal data was held in as few places as necessary, never shared informally, particularly via email, and never transferred outside of the European Economic Area. All data was encrypted before being sent electronically.

Participants were entitled to ask what information was held about them and why; ask how to gain access to it; know how it was kept up to date; and how the researchers were meeting their data protection obligations.

Analysis

In total 48 hours of data were coded, 4 hours per night. For each coded file imported into SPSS, descriptive statistics were computed, and data tested for normality. Where appropriate, parametric and non-parametric tests were performed to address the hypotheses.

Data from the enrolment form (Appendix 4) were extracted into an Excel spreadsheet linked to each participant's anonymous study ID. Maternal and infant age was determined as the respective ages on the day of enrolment, based on the birthdates provided on the enrolment form.

Results

Participant characteristics

12 mother-baby dyads that met the inclusion criteria took part in the study. Although participants were informed that they could stop participating in the study at any time, none chose to do so. Infants were aged 0 to 4 months (mean age 3.66 months, standard deviation (SD) = 3.25, 6 males). Mothers were 27 to 43 years old (M = 31.91 years, SD = 5.12), were married (75%) or living with partner (25%). Mothers had university-level education (58%) and some had post-graduate-level education (42%). All defined themselves as white British and all had a family income of over £40k.

Hypothesis 1

Table 12 Swaddling affects feed frequency and duration in breastfed infants

	Unswaddled n=12	Swaddled n=12	p
Feed frequency (median per 4-hour period)	3.00	1.00	.007
Feed duration (median per bout)	8.26 minutes	8.05 minutes	.764

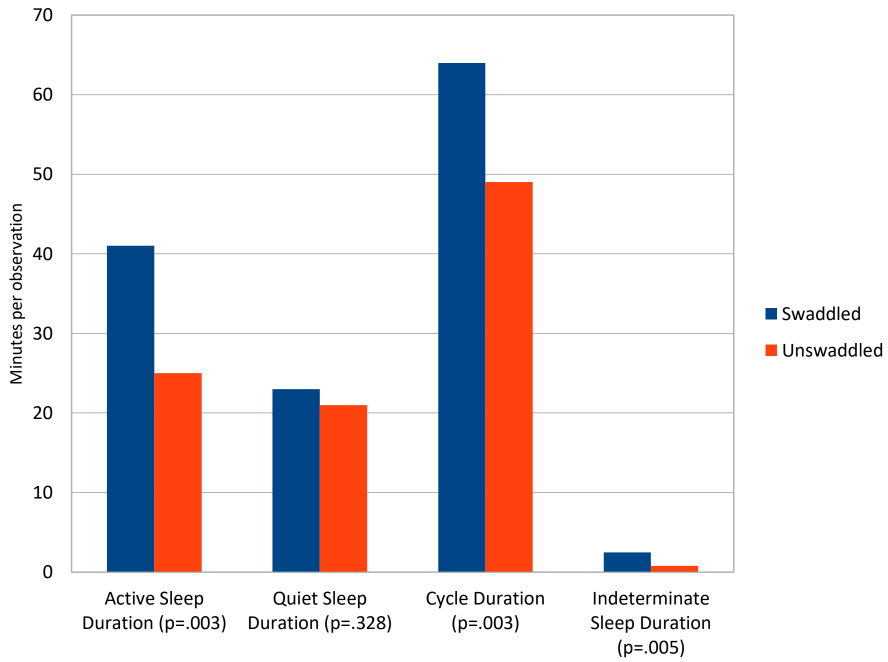
For coding criteria, see page ...

As the Feed Frequency data did not meet the assumptions of normality (p<.05), a nonparametric test, the Wilcoxon Signed-Ranks for paired samples, was performed. The results indicate a significant difference in feed frequency between swaddled and unswaddled nights (T=1.50, N=10, p<0.5; 95% conf. interval). The magnitude of the feed frequency difference was determined for each infant, and across all infants the median difference was 2 fewer feeds on swaddled nights than on unswaddled nights (N=12, p=.007). Although the null hypothesis can be rejected, caution should be given to the presence of two tied ranks that reduced the sample size from 12 to 10 for this calculation.

As the Feed Duration data satisfied the assumptions of normality (p>.05), a parametric test, the dependent t-test was performed. Despite lower feed frequency, there was no significant difference in feed duration between swaddled and unswaddled conditions (t(11)=.308, N=12, p=>.05). Therefore, in relation to hypothesis 1, swaddling was associated with reduced frequency of breastfeeds but there was no significant reduction in the duration feeds in this sample of infants.

Hypothesis 2

Hypothesis 2: Swaddling affects sleep state duration in breastfed infants.



As the data did not meet the assumptions of normality, a Wilcoxon Signed-Ranks test for paired samples was performed on each variable. With regard to sleep state, infants spent significantly more time in active sleep when swaddled than when unswaddled (T=66.00, N=11, p<0.03; 95% CI). The difference was determined for each infant. Calculation of the median difference across all infants revealed that they spent on average 16 minutes longer in active sleep per sleep cycle when swaddled than when unswaddled (N=11, p=0.03). In fact, infants spent an average 64% of their sleep cycle in active sleep when swaddled (41 minutes out of 64 minutes), compared with 51% when unswaddled (25 minutes out of 49 minutes). Conversely, there was no significant difference in duration of quiet sleep between swaddled and unswaddled conditions (T=44.00, N=11, p=.328).

With regard to sleep cycles, the Wilcoxon Signed-Ranks test indicated a significant difference in cycle duration between swaddled and unswaddled nights (T=66.00, N=11, p=0.03; 95% conf. interval). The difference was determined for each infant. Calculation of the median difference across all infants revealed that they had a cycle length on average 18 minutes longer when swaddled than when unswaddled (N=11, p=.002).

Although the null hypothesis can be rejected, when examining cycle duration, caution should be given to the presence of missing data for one infant on the unswaddled night; for this reason, that infant was excluded from the analysis, reducing the sample size from 12 to 11 for this calculation. Caution should also be given to the presence of a number of tied ranks which reduced the sample size of each calculation respectively.

Table 13 Hypothesis 2 Tied Ranks

Variable	# of tied ranks	Resulting sample size
Active Sleep Duration	1	n=11
Cycle Duration	1	n=11

Although infants had longer sleep cycles when swaddled, the Wilcoxon Signed-Ranks test did not find a significant difference in the number of cycles between swaddled and unswaddled nights (T=13.00, N=11, p=.864). The median number of cycles per 4-hour observation was 2.

As the data concerning indeterminate sleep duration satisfied the assumptions of normality (p>.05), a parametric test, the dependent t-test was performed. The results indicate that there was no difference in the median duration of indeterminate sleep between swaddled and unswaddled nights (t(11)=-3.333; p<.05). Calculation of the median difference across all infants revealed that time spent in indeterminate sleep differed by an average of 59 seconds between swaddled and unswaddled nights (N=10, p=.016).

Therefore, in relation to hypothesis 2, in this sample swaddling was associated with a longer cycle length than non-swaddling, specifically increasing the length of time spent in active sleep. There was no significant effect of swaddling upon quiet sleep duration or duration of time spent in indeterminate sleep in this sample of infants.

Hypothesis 3

Figure 32 Swaddling affects the type and frequency of mother/infant interaction

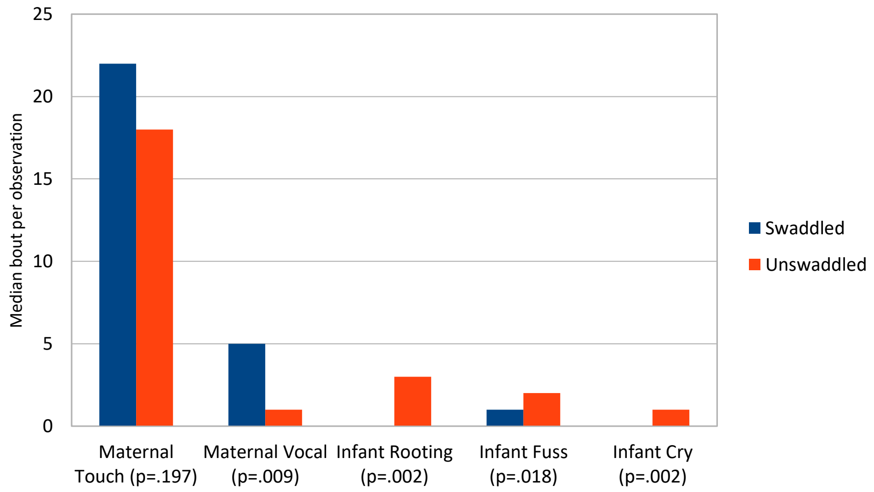
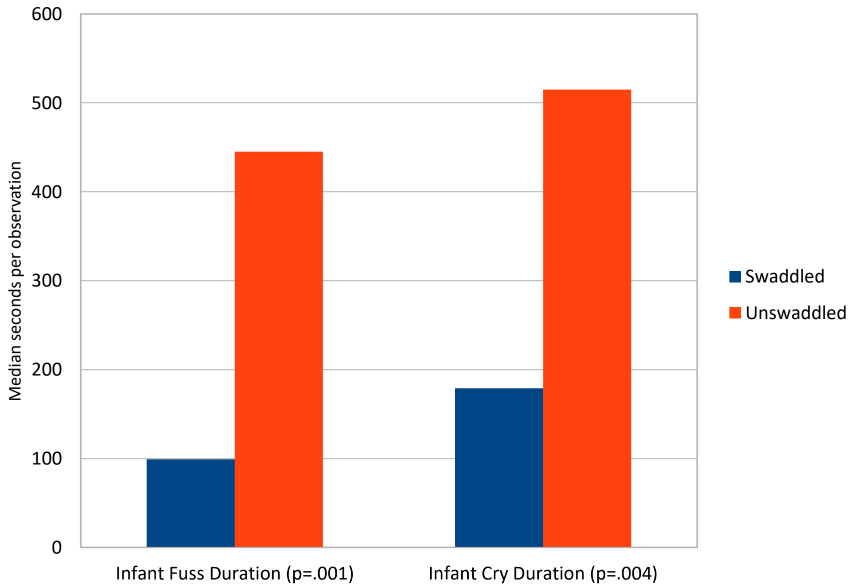


Figure 33 Swaddling affects the type and frequency of mother/infant interaction (b)



Mothers touched their infants slightly more on swaddled nights (mean 22 times) than on unswaddled nights (mean 18 times). However, this difference was not statistically significant (P=.197).

The Fuss Duration data and Cry Duration data met the assumptions of normality (p>.05), therefore a dependent t-test was performed on each. The results indicate that infants spent significantly less time fussing (t(11)=-4.500; p=.001) and significantly less time crying (t(11)=-3.624; p=.004) whilst swaddled than unswaddled.

The remaining data did not meet the assumptions of normality (p<.05), therefore a Wilcoxon Signed-Ranks test for paired samples was performed on each. The results indicate a significant difference between swaddled and unswaddled nights for the variables: Maternal vocal Frequency (T=72.00, N=12, p=.009; 95% CI), Rooting Frequency (T=00.00, N=12, p=.002; 95% CI), Fuss Frequency (T=3.00, N=12, p=.018; 95% conf. Interval), and Cry Frequency (T=.00, N=12, p=.002; 95% CI).

Calculation of the median difference of each variable across all dyads indicated that mothers' vocal communication differed by an average of three utterances between swaddled and unswaddled observations (n=12, p=.009); Further, infants made 2.5 more rooting attempts (n=12, p=.002), fussed one additional time (n=9, p=.002) and cried one additional time (n=11, p=.002) on average when unswaddled than when swaddled. With regard to Cry Duration, calculation of the median difference across all infants indicated that they cried on average 5.8 minutes (35%) longer on the unswaddled night than on the swaddled night (n=12, p=.004).

Although the null hypothesis can be rejected, caution should be given to the presence of a number of tied ranks which reduced the sample size of each calculation respectively. See table 14.

Table 14 Hypothesis 3 Tied Ranks

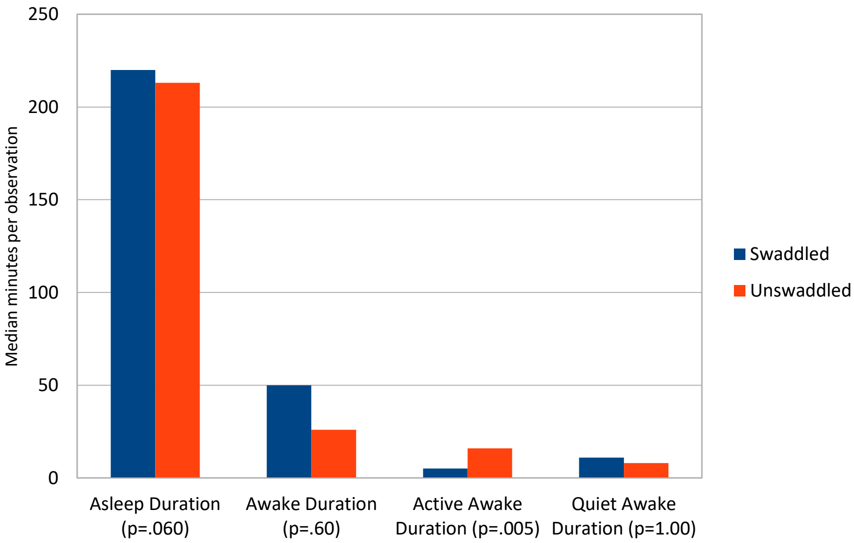
Variable	# of tied ranks	Resulting sample size
Cry Frequency	1	n=11
Fuss Frequency	3	n=9

The Wilcoxon Signed-Ranks test failed to find a significant difference in Touch Frequency between swaddled and unswaddled nights (T=47.50, N=12, p=.19).

Therefore, in relation to Hypothesis 3, for this sample of dyads swaddling appeared to influence the number of maternal vocalisations. The intervention also appeared to reduce the number of infants' rooting, fussing and crying attempts and to shorten the length of those attempts. Swaddling did not appear to influence touch-based interactions in this sample of dyads.

Hypothesis 4

Figure 34 Swaddling produces a cumulative 'dampening' effect on infant arousal



As none of the data for this hypothesis met the assumptions of normality (p<.05), Wilcoxon Signed-Ranks tests for paired samples were performed.

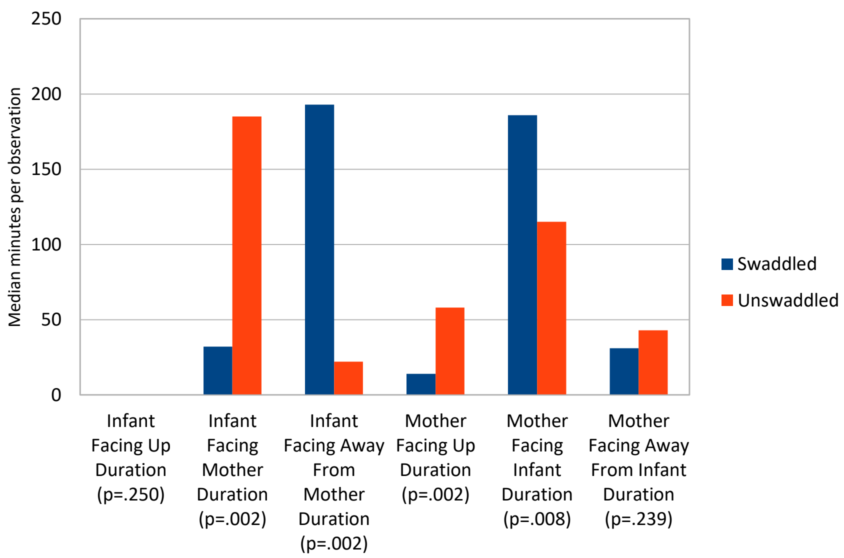
Overall, the results indicate no significant difference in sleep duration between swaddled and unswaddled nights (T=63.00, N=12, p=>.005). Although there was no significant difference in time spent awake when swaddled versus unswaddled (T=15.00, N=12, p=>.005), infants spent significantly less time in an active awake state when swaddled (T=03.00, N=12, p=.005; 95% conf. Interval). In fact, calculation of the median difference of Active Awake across all dyads indicated an average difference of 12 minutes between swaddled and unswaddled conditions. Infants spent an average of 62% of their total awake time in an active awake state when unswaddled compared with just 25% when swaddled over the 4 hour window of observation.

The results did not indicate a significant difference in the duration of quiet awake between swaddled and unswaddled conditions. There were no tied ranks.

Therefore, in relation to Hypothesis 4, swaddling did not affect the length of time the infants of this sample spent asleep or in a quiet awake state. The intervention did however appear to significantly reduce the time the infants spent in an active awake state.

Hypothesis 5

Figure 35 Swaddling discourages face-to-face sleeping orientation in mothers and infants



The data for this hypothesis did not meet the assumptions of normality (p<.05), therefore a Wilcoxon Signed-Ranks test for paired samples was performed on each variable. The results indicate a significant difference between swaddled and unswaddled nights for the variables: Infant Facing Mother Duration (T=-3.059, N=12, p=.002; 95% conf. Interval), Infant Facing Away From Mother Duration (T=3.059, N=12, p=.002; 95% conf. Interval), Mother Facing Up Duration (T=-3.059, N=12, p=.002; 95% conf. Interval), and Mother Facing Infant Duration (T=2.667, N=12, p=.002; 95% conf. Interval).

Calculation of the median difference of each variable across all dyads indicated that infants faced their mother on average 43 minutes longer when unswaddled than when swaddled (n=12, p=.002). Further, there was an average of 170 minutes difference in the amount of time infants spent facing away from their mothers when swaddled than when unswaddled (n=12, p=.002). In fact, swaddled infants only faced their mother for an average of 15% of their total sleep during the 4 hour window of observation (32 minutes versus an average total sleep time of 213 minutes). In contrast, on average mothers faced their infants 62 minutes longer on the swaddled night (n=12, p=.008), the equivalent of 89% of their infants total observed sleep time. Mothers also spent an average of 42 minutes longer facing upwards on the unswaddled night (n=12, p=.002).

The Wilcoxon Signed-Ranks test failed to find a significant difference in the time mothers spent facing away from their infants on swaddled and unswaddled nights (T=24.000, N=12). As no infants spent time facing up, a comparative test was not performed for this variable. There were no tied ranks.

Therefore, in relation to hypothesis 5, in this sample of dyads swaddling appeared to negatively influence the duration infants spent facing their mother during sleep yet positively influence the duration that mothers' spent facing their infants during sleep. There did not appear to be a significant association between swaddling and the amount of time mothers spend looking away from their infants in this sample.

Table 15 Results summary

Hypothesis	**Outcome**
Hypothesis 1: Swaddling affects feed frequency and duration in breastfed infants.	Hypothesis partially supported. Swaddling affects feed frequency.
Hypothesis 2: Swaddling affects sleep state duration in breastfed infants.	Hypothesis partially supported. Infants had longer sleep cycles when swaddled. Infants spent more time in active sleep when swaddled.
Hypothesis 3: Swaddling affects the type and frequency of mother/infant interaction.	Hypothesis partially supported. Swaddling influenced number of maternal vocalisations. Swaddling reduced number of infants rooting, fussing and crying attempts. Swaddling shortened the length of those attempts.
Hypothesis 4: Swaddling produces a cumulative 'dampening' effect on infant arousal.	Hypothesis partially supported. Swaddling reduced duration of active awake.
Hypothesis 5: Swaddling discourages face-to-face sleeping orientation in mothers and infants.	Hypothesis partially supported. Swaddling reduced duration infants' spent facing mother during sleep. Swaddling increased duration mothers' spent facing their infants during sleep.

Discussion

Since the sample size was not large, the results discussed are indicative rather than conclusive, and no firm conclusions are drawn about the specific effects of swaddling; instead, this discussion is intended to give an overview of the pertinent issues raised by the use of this novel intervention for these infants.

Sleep Duration

Contrary to the original hypothesis, this sample of breastfed infants did not spend more time asleep while swaddled than while unswaddled. Although this finding conflicts with largely historic studies associating swaddling with longer sleep duration (Lipton, Steinschneider et al. 1965, Caglayan, Yaprak et al. 1991, Meyer and Erler 2011), it is supported by contemporary studies that also failed to observe a difference in sleep duration between swaddled and unswaddled conditions (McRury 2010, Richardson, Walker et al. 2010, Kelmanson 2013). It is possible that modern studies apply more sophisticated technology to determine sleep status than the purely visual approach typical of historical studies.

The outcome is unlikely to be explained as resulting from the novel lab environment; Firstly, there was no statistically significant difference in sleep duration across conditions despite the randomisation of starting condition (swaddled versus unswaddled) delimiting 'first night effect' (Edinger, Fins et al. 1997, Herbst, Metzler et al. 2010). Secondly, use of a lab environment is common in videosomnographic sleep research. Studies that have found swaddling to lengthen sleep (Meyer and Erler 2011) and those that have found swaddling produced no difference to sleep length (Richardson, Walker et al. 2010) were also conducted in sleep labs.

Rather, the similar sleep durations observed across conditions in the present study could be explained by age, swaddle technique, and/or feeding mode. For instance, there may have been ontogenetic differences between the subjects in the present study and the subjects of previous studies. In one study swaddling did not prolong sleep time at 3 to 4 weeks age but however *did* at 3 months (Richardson, Walker et al. 2009).

In addition to age of user, swaddle technique is a baseline dynamic of the intervention. For instance, it has been suggested that the sedative effects of swaddling are "triggered by very specific stimuli delivered above a certain threshold" (Karp 2012)(p67). However, many swaddling studies have failed to describe the precise swaddle technique used. Narangerel and colleagues, for instance, gave a very brief description of their swaddle technique, namely "two or three layers of cloth that enclosed the trunk and arms up to infant's neck" (Narangerel, Pollock et al. 2007)(p262). Further, both McRury and Kelmanson failed to provide any description of swaddle technique (McRury 2010, Kelmanson 2013). As detailed in the sociohistorical review (Chapter 3) and the survey (Chapter 9), swaddle techniques differ vastly both across and within cultures. Arms can be placed outside the swaddle, inside the swaddle with hands by the face, inside the swaddle across the chest (as in the present study), or down by the sides. Insufficient description of swaddle technique is present to certain degrees across all studies meaning it is unclear whether the interventions are similar enough to synthesise.

All previous swaddle studies, bar one, have failed to ascertain whether infants were breast or formula fed (Dixley 2015), yet this variable is a crucial determinant of sleep behaviour. The only previous swaddle study to ascertain feeding mode also restricted its focus to breastfeeding subjects and produced the same sleep duration outcome as the present study (Richardson, Walker et al. 2010). As detailed in the literature review, breastfeeding dyads are physiologically programmed to feed at night, a time during which lactation hormones are acutely sensitive (Carey 1975, Ball and Russell 2012). Without this biobehavoural drive, infants fed artificial milk may be more susceptible to the pacification effects of swaddling and thus more likely to demonstrate lengthier sleep. The studies on which the assumption of longer sleep is based (Lipton, Steinschneider et al. 1965, Caglayan, Yaprak et al. 1991, Meyer and Erler 2011) were largely conducted prior to global breastfeeding initiatives. The disproportionate sleep duration observed in those studies may therefore reflect the well-acknowledged hegemony of formula feeding in sleep research, particularly during that era (Alexeyeff 2013, Ball 2017, Tomori, Palmquist et al. 2017, Ball 2019, Ball, Tomori et al. 2019).

Sleep States

To date, a largely neglected area of infant sleep and arousal is the interaction between interventions and sleep states. Understanding sleep-awake states is fundamental to understanding infant wellbeing. Sleep-awake states are behavioural indicators of the integrity of the infant neurobehavioral system, with changes in state illuminating the system's regulatory controls (Wagner 1937, Wolff 1959, Prechtl 1977, Thoman 2001). In exploring sleep states, the present study contributed to a research gap that has endured for almost two decades. “The difference in the physiologic effect of swaddling in QS and AS sleep” (van Sleuwen, Engelberts et al. 2007)(p1100) is a knowledge deficit identified by two systematic reviews (van Sleuwen, Engelberts et al. 2007, Dixley 2015). In the present study, two significant findings were pertinent to this area of enquiry: 1. Swaddling was associated with increased sleep cycle length and decreased sleep cycle frequency. 2. Swaddling was associated with a greater duration of active sleep. As finding 1 is interlinked with finding 2, both are now discussed under the umbrella of sleep states.

When swaddled, infants in this study spent more time in active sleep (AS) but not quiet sleep (QS). Animals exposed to immobilisation have also exhibited an increase in REM sleep (Van Reeth, Weibel et al. 2000). The outcome conflicts with previous human studies that found swaddling to increase length of QS (Franco, Seret et al. 2005, Meyer and Erler 2011), but supports those which found swaddling to increase the length of AS (Brackbill 1975, Gerard, Harris et al. 2002). Any discussion, therefore, needs to consider the methodological variation across this emerging knowledgebase. Recall that many studies omit to describe swaddle technique in sufficient detail to enable a robust synthesis across the knowledgebase (Narangerel, Pollock et al. 2007, McRury 2010, Kelmanson 2013). Failure to ascertain feeding mode is another deficiency in this subject area. All the above studies did not distinguish whether infants were breast or formula fed (Dixley 2015), yet in addition to impacting sleep duration, this variable is also known to influence sleep states. Infants fed artificial milk experience a greater degree of AS than their breastfeeding counterparts (Harper, Hoppenbrouwers et al. 1976, Butte, Jensen et al. 1992, Ball and Klingaman 2007). In focusing on exclusively breastfed infants, the present study eliminated the confounding influence of feeding mode. Under swaddled conditions, the trends discovered in this sample of exclusively breastfed infants seem to align with the expected behaviour of unswaddled formula fed infants.

Based on a thorough reading of the literature, four interrelated theories are advanced to explain the disproportionate increase in AS observed in the present study. The first concerns proprioception. As detailed in the literature review, this concept is defined as the ability to sense and understand body movements and keep track of one's body position in space, a process controlled by the cerebellum. This area of the brain only quietens during AS (Grigg-Damberger 2016). It is possible that the motor restraint of swaddling interacts with the cerebellum, discouraging the transition to quiet sleep. Sometimes, a feature of the transition from active to QS, is a sudden muscle spasm called a hypnagogic startle (Lewis 2006, Irving 2020). The action of swaddling in preventing or minimising the hypnagogic startle may undermine the transition to QS.

Another theory to explain the disproportionate representation of AS under swaddled conditions centres on the stress hypothesis presented in the literature review. This theory complements the previous one by citing the transition process from AS to QS and expanding on the above theory by exploring the nature of AS. This sleep state is characterised by a high degree of amygdala activation. In mammals the amygdala is integral to the appraisal of dangerous situations, the response to threat and to prediction of the circumstances when these are likely to occur (Horne 2000). Relatedly, AS is also characterised by increased activation of the central nervous system (Hess, Mills et al. 1987, McNamara, Wulbrand et al. 1999). During AS, a switch from the sympathetic to the parasympathetic nervous system encourages movement into QS (Faure and Richardson 2006). If swaddling does in fact elicit a stress response, engagement of the sympathetic nervous system would favour prolonged AS. This hypothesis is strengthened by sleep data involving adults. Bonnet and Arand investigated heart rate variability in the context of sleep state and found that "increases in central nervous system sympathetic activity precede and possibly play a role in the initiation of REM sleep and arousals during sleep" (Bonnet and Arand 1997) (p395).

A significant factor predicting how much REM (adult equivalent of AS) is demonstrated by animals is safety when sleeping (Allison and Cicchetti 1976). After immobilization stress, rats exhibit a significant increase in REM sleep, a phenomena termed 'immobilization-induced REM sleep rebound' (Rampin, Cespuglio et al. 1991, Descamps and Cespuglio 2010). Even relatively short (1 hour) periods of immobilization stress are associated with significant rises in REM. This noticeable increment following stress has also been observed in humans, where it has been termed "an adaptive coping strategy" (Machado, Rocha et al. 2017)(p39). Here, "the REM process serves to maintain the central nervous system in a state of physiological readiness so that it may react swiftly to the exigencies of the real world" (Roffwarg, Muzio et al. 1966)(p618). Indeed, the same neuropeptide responsible for regulating the stress response also regulates REM and indeed can induce REM (Rampin, Cespuglio et al. 1991, Nollet, Hicks et al. 2019). In this vein, some scholars maintain that REM allows fleeting glimpses at the environment to check for danger - the Sentinel Hypothesis (Snyder, 1966, as cited in Horne 2000). Indeed, a distinct characteristic of REM is that the organism has awareness of its acoustic environment, and this awareness does not habituate. REM therefore demonstrates "an unusual wakefulness wherein the individual has such an intense level of orienting responses" (Horne 2000)(p792). In ecologies of threat, the need for such brief 'awakenings' is increased. Adopting a developmental view, some scholars posit that "long consolidated REM episodes are essential for elaboration and integration of traumatic memories into the autobiography" (Suchecki, Tiba et al. 2012)(p41). Therefore, when taken in conjunction with the infant orientation data, the present findings suggest swaddling was experienced by the infants as a form of maternal deprivation. Consequent activation of the stress response might have made it more difficult for infants to enter QS and when they did, made QS more difficult to maintain. This phenomenon has been observed in infants separated from their mothers (Morgan, Horn et al. 2011).

A third theory to explain the predominance of AS involves the process of habituation and centres upon the novel nature of swaddling to the infants in the present study. This theory does not negate the stress hypothesis but rather complements it if one considers the potentially stressful nature of a sudden loss of motor responses. Indeed, Revonsuo proposed that the main function of active/REM sleep is to process stressful daily experiences (Revonsuo 2000)[15]. This adaptive response, seen across mammal species including primates and humans, has been hypothesised to protect the organism from excessive sympathetic reactivity accumulated during the day (Tsoukala 2018).

In the context of regulatory responses, AS is thought to facilitate neural adaptation through synapse formation and pruning (Roffwarg, Muzio et al. 1966, Denenberg and Thoman 1981, Mirmiran and Ariagno 2003). Evidence from animal studies suggest that such learning in response to a novel stimulus occurs in both awake and AS states, whereas no new associative learning occurs during QS (Maho and Bloch 1992, Hennevin, Hars et al. 1995). Some hypothesise that associative learning during sleep could be state dependent for human infants as well (Tarullo, Balsam et al. 2011).

Indeed, studies involving human infants have highlighted a possible link between sleep state and response to a novel stimulus. In a series of studies, a novel tactile stimulus was applied to the foot of infants at frequent intervals. Infants' initial reaction was foot withdrawal, followed by a sigh, startle, thrashing, and cortical arousal. After repeated stimuli, reactions were gradually eliminated starting with cortical activity, then startle followed by sighs and foot withdrawal. Interestingly, the results across studies indicated rapid habituation occurred if the stimuli were administered during AS rather than QS (McNamara, Wulbrand et al. 1997, McNamara, Wulbrand et al. 1999). AS is also associated with rapid habituation to olfactory stimuli (Murray and Campbell 1970). Further, previous studies have highlighted the role of the REM sleep in the memory consolidation of adults (Siegel, 2001, Tononi and Cirelli, 2014, Calais et al., 2015, Touzet, 2015, Menz et al., 2016, , as cited in Cecchini, Iannoni et al. 2017) and infants (Cecchini, Iannoni et al. 2017). It is thus possible that the infants in the present study spent more time in AS whilst swaddled as an orienting response because this sleep state is the primary route to memory consolidation and habituation during sleep.

The final theory advanced to explain the increased length of AS during swaddling focuses on the possible thermogenic impact of swaddling. Associated with an increased risk of hyperthermia (Fleming, Gilbert et al. 1990, Gilbert, Rudd et al. 1992), swaddling provides insulation, reducing the emissivity of the skin and changing airflow patterns around the infant (Thomas 1994, Silva, Laszczyk et al. 2016). In addition to this, the intervention poses a

[15] Revonsuo acknowledges this is his proposal and more research is needed to ascertain if this is so.

behavioural hurdle to effective temperature regulation by preventing postural adaptation (Bach, Telliez et al. 2000, Bach, Telliez et al. 2002, Faure and Richardson 2006). Responses to thermogenic compromise are particularly germane during the first three months of life - the most common swaddling window and a peak age risk for SIDS – when an infant's immature thermoregulatory system undergoes complex developmental changes (Azaz, Fleming et al. 1992). As detailed in the literature review, thermoregulatory responses differ according to sleep state. In contrast to adults who experience impairment of thermoregulation during REM sleep (Parmeggiani and Rabini 1970), infants experience maintained or sometimes even enhanced thermoregulation during AS, their version of REM (Bach, Telliez et al. 2002). Building on the previous theory, this hypothesis recognises habituation as an adaptive response and proposes that an increase in AS occurs in reaction to thermogenic compromise.

Potential implications

Moving from the potential *causes* of the present sleep state outcomes, the discussion will now explore possible epidemiological *consequences*.

During AS, the muscles of breathing (except the diaphragm) are paralyzed, making respiration less efficient (Givan 2003). Breathing is irregular and relatively uncoupled from its usual regulatory mechanisms (Baker and McGinty 1977, Siegel 2005). A lower rate of respirocardical coordination is observed more often in AS than in QS (Giddens and Kitney 1985, Rother, Zwiener et al. 1988, Frasch, Zwiener et al. 2007) with likelihood of apnea episodes during sleep shown to increase (Steinschneider 1972, Berterottiere, D'Allest et al. 1990). In their study, Gerard and colleagues found that increasing swaddle pressure resulted in increased respiratory rate during QS but not AS (Gerard, Harris et al. 2002). In addition, the team also found that swaddled infants experienced a small but significant heart rate increase in AS but not QS, a finding that was mirrored in subsequent research (Richardson, Walker et al. 2010). These outcomes highlight the decoupling of cardiorespiratory regulatory mechanisms during AS under swaddled conditions. Furthermore, it is normally much easier to be awakened during AS than QS, yet when swaddled, infants have shown an overall decrease in arousability, even during AS (Richardson, Walker et al. 2010). Arguably, for infants with inbuilt arousal deficiencies, swaddling may therefore be hazardous. Of further concern is feeding mode. During AS, formula fed infants are less able to arouse than their breastfeeding counterparts (Horne, Parslow et al. 2004). Further studies should determine whether the present findings are replicated in formula fed infants, and if so, what this means for risk assessments.

In sum, the sleep state findings of the present study support previous data showing that environmental factors impact the organisation of sleep states (Freudigman and Thoman 1998). In the context of regulatory responses, prolonged AS may be an adaptive reaction to novel stimuli (in this case, swaddling).

Awake Characteristics

Swaddling did not affect the length of time the infants of this sample spent in a quiet awake state during the 4-hour coding window. However, as predicted, swaddling was associated with a reduced duration of time infants spent in an 'active awake' state. This finding mirrors previous data (Lipton, Steinschneider et al. 1965) and is unsurprising given that motor restraint is a baseline dynamic of swaddling. However, there are methodological and ontological reasons why this outcome may be worth considering further.

For a behaviour to be coded as active awake the taxonomic definition required 'eyes open' in conjunction with 'motor activity and/or vocalisations.' Within this framework, vocalisations could include 'crying or fussing'. Crucially, motor restraint does not prohibit vocalisations, yet as discussed below, under swaddled conditions infants engaged in less vocalisations in terms of both frequency and duration. Furthermore, although swaddling does indeed restrict many forms of motor activity, particularly of the arms, such activity (albeit reduced) was shown under swaddled conditions in the present study via distinctive ways. For instance, some 'active awake' swaddled infants could be observed lifting both legs at the same time, therefore elevating the swaddle pod up from the mattress to the infant's waist point. Similar versions of this activity were observed in infants that manoeuvred and wiggled around in a worm-like fashion. Each instance met the definition for active awake. With these methodological and ontological factors in mind, the link found in the present study between swaddling and a quiet awake state warrants further exploration. The reduction of active awake during swaddling correlated with a reduction of infant-initiated interaction attempts. Communicative discord between the infants and their mothers during swaddling was further reflected in reduced feeding attempts, reduced infant vocalisations and reduction of time spent facing their mothers. Implications of this are discussed below.

Dyad Interaction

As detailed in the literature review, both mothers and infants play interactive roles in their biobehavioural relationship (Feldman 2007, Feldman 2012). Reading cues and responding to specific actions enables both mother and infant to attune with each other for their mutual biobehavioural benefit. In coding the behaviours of both infant and mother, this study acknowledged the anthropological insight that "it is the dyad, and not the infant, that constitutes the major unit for study and analysis" (McKenna 2004)(p513). Underpinned by this understanding, the discussion will now explore maternal interactive outcomes followed by infant interactive outcomes.

The present findings do not support the hypothesis advanced by previous scholars that swaddling reduces instances of maternal touch (Ferber, Kuint et al. 2002, van Gestel, L'Hoir et al. 2002). Furthermore, the findings conflict with previous Russian data showing that swaddling decreased mothers' physical responsiveness to their infants (Bystrova, Ivanova et al. 2009). Differences in culture and parenting style may explain this contrast. Infant age may also be influential. The Russian infants were observed during the period immediately following delivery, at a time of maternal fatigue. The consistent tactile responsiveness of mothers in the present study may be a response to the introduction of a novel intervention to an already established reciprocity pattern. Further, the mothers of Russian newborns knew their infants had no other experience. In contrast, mothers in the present study were aware that swaddling was a novel intervention for their infants, and it would be reasonable to anticipate they might attempt to reassure their infants with touch and vocalisations. One might expect more touching on both nights for reassurance, but particularly on the swaddled night. Had the infants been habituated to swaddling, mothers may have touched them less.

In contrast to touch-based interactions, swaddling influenced the number of maternal vocalisations with some mothers talking to their infants more while swaddled, and others less. This difference may be attributed to parenting style. An eclectic range of parenting styles have been noted within Western society, as influenced by life history, maternal personality, and infant characteristics (Porter, Hart et al. 2005, Chan and Koo 2011, Arnott and Brown 2013, Sangawi, Adams et al. 2015).

Relative to maternal outcomes, swaddling had more impact on the interactive outcomes of the infants in the present study. For instance, infants made significantly fewer rooting attempts when swaddled than when unswaddled. This finding can be explained by the inability of swaddled infants to engage in hand-to-mouth rooting, a common early hunger cue (NCAST 1990) and an item on the rooting taxonomy. When taken in conjunction with feed data, this finding illustrates the importance of hand-to-mouth rooting as a primary infant signalling strategy. One obvious short-term risk of less rooting is that the infant has less opportunities to suckle. As underscored in the literature review, the physiology of breastfed infants is adapted to frequent or 'continuous' feeding (Lozoff and Brittenham 1979, Konner and Worthman 1980, Mosko, McKenna et al. 1993).

Regarding vocalisations, not only did infants demonstrate less fussing and crying bouts on the swaddled night, the durations of these behaviours were also shorter. Although these outcomes reflect a vast body of previous data (Campos 1989, van Sleuwen, L'Hoir M et al. 2006, Caiola 2007, Karp 2007, Akhnikh, Engelberts et al. 2014, Edraki, Paran et al. 2014), their causative mechanism remains unclear. A reduced rate of crying has been found in traditional cultures where the mother 'wears' the infant on her body for extended periods (Reese 2000, Maldonado-Duran and Lecannelier 2019).

Another explanation centres on the interaction between swaddling and infantile reflexes. As the Moro reflex is associated with crying (Clarke, Hunt et al. 1937, Brucknerova, Holomanova et al. 2012, Rousseau, Matton et al. 2017), it is possible that swaddling reduces crying by dampening this reflex. Though failing to mention startles specifically, van Slauwen and colleagues suggest that swaddled infants cry less because motor restraint decreases their level of "reactivity" and "jitteriness" (van Sleuwen, L'Hoir M et al. 2006)(p516).

Potential implications

The reduction of crying/fussing associated with swaddling may have negative consequences for infant nutrition. A vast knowledgebase authoritatively demonstrates that quality of maternal caregiving is intrinsically linked to differences in infants' communication strategies (Kogan and Carter 1996, Kennedy, Rubin et al. 2004, Moore, Hill-Soderlund et al. 2009). Crying has aptly been referred to as a "biological siren", the primary purpose of which is to alert caregivers to the needs of the infant (Zeskind and Lester 2001)(p149). In Western industrialised societies, crying is the most commonly reported hunger cue used by mothers to initiate feeding (Gross, Mendelsohn et al. 2016). In sum therefore, the present findings indicate that swaddling may create a sub-optimal interactive style in mothers and infants, objectively measured by dyadic mutuality, with possible biobehavioural consequences.

Dyad Orientation

On average, mothers faced their infants significantly longer on the swaddled night and faced upwards significantly longer on the unswaddled night. This apparent increase in maternal vigilance during swaddled conditions and relatively decreased attentiveness during unswaddled conditions, may reflect the novel nature of swaddling to this sample of dyads. Keeping the infant within visual proximity is a common form of vigilance behaviour amongst diurnal primates (Kutsukake 2007). It is likely illustrative of mothers' surveying the novel situation, a maternal version of the orientating response.

Arguably more illuminating are the outcomes pertaining to infant facial orientation. When unswaddled, infants' preference for maternal-facing orientation mirrored data from previous room-sharing studies of breastfed infants (Richard, Mosko et al. 1996, Ball and Klingaman 2007). However, when swaddled, the preference of facing away from the mother is at odds with the nature of breastfeeding as promoting face-to-face sleep orientation.

The reduction in infants' maternal-facing orientation under swaddled conditions is further noteworthy considering the natural infant preference for right-facing (Barnes, Cornwell et al. 1985). In the spatial context of the present lab environment, right-facing translated to a maternal-facing orientation. Interestingly, gaze aversion is a believed to be self-regulatory behaviour that infants adopt when feeling overwhelmed (Koulomzin, Beebe et al. 2002, Faure and Richardson 2006, Durier, Henry et al. 2015). Head turned away is categorised as 'disengaging' behaviour by tools of infant assessment (NCAST 1990, White and Bryan 2002). Studies show infants engage in gaze avoidance following a sudden and unexpected separation from their mother (Papousek 2007, Salomonsson 2016). In a similar vein, scholars have observed a prevalence of gaze avoidance in scenarios where an infant's "human partners fail in their protective function and he is exposed to repeated and prolonged experiences of helplessness" (Fraiberg 1982) (p614). In this psychoanalytic model, looking away serves as a "cutoff mechanism" (p632) and illustrates "attachment resistance" (Margolis, Lee et al. 2019)(p10).

Finally, infant avoidance of the 'face up position' across both swaddled and unswaddled conditions is a common phenomenon observed in previous infant sleep studies and is believed to have no association to maternal proximity (Brown, Klingaman et al. 2005).

Breastfeeding

> *"Infants who can feed, do. Infants who do not feed, cannot"*
> (Tow and Vallone 2009)(p627).

In the present study, swaddling was associated with reduced feed frequency but not feed duration. As the literature on night-feeding swaddled infants is sparse, it is difficult to compare these results with any existing knowledgebase. Studies of infant-mother proximity have shown a two-fold decrease in number of breastfeeding episodes when an infant slept solitarily in comparison to co-sleeping (McKenna, Mosko et al. 1997, Gettler and McKenna 2011). This comparison would support the theory presented above, that infants may exhibit dissociative behaviour while swaddled, akin to solitary sleeping (Richard, Mosko et al. 1996).

Many infant hunger cues involve the arms. Mouthing hands or objects, fidgeting, muscle tension such as clenching fingers or fists over the torso, and flexion of the arms and legs are all common cues that feeding is required (Harvey and Haldeman 2006, Hodges, Hughes et al. 2008, Ladewig, London et al. 2017). If a mother fails to notice these hunger cues, her infant may become hungrier until upset and crying. At this stage, the mother may become stressed, which can be sensed by the infant. The sum of these factors may considerably lengthen time between feeds (Gill and Vierheller 2015).

Swaddling arguably has dual impact on this fundamental process, a potential explanation for the reduced feed frequency observed in the present study. Firstly, by binding the arms, swaddling obscures the bulk of infant feeding cues. In this context, data show that even visual obscuring via the wall of a hospital bassinette placed next to the maternal bed results in fewer feeding bouts (Ball, Ward-Platt et al. 2006). Secondly, mothers may feed only in response to fussing/crying, known as the ‘feed to soothe’ effect (Black and Aboud 2011). It follows therefore, that as infants cried less whilst swaddled, they were fed less. Indeed, as detailed in the literature review, the association between cry reduction and feed reduction has underpinned the promotion of swaddling alongside other non-feeding soothe strategies to combat rising childhood obesity (van Sleuwen and L’Hoir 2007, Redsell, Atkinson et al. 2011, Gross, Mendelsohn et al. 2016). Randomized controlled trials of this approach have demonstrated fewer nocturnal and daily feeds from age 3 to 16 weeks compared to control group infants and slower weight gain over the first year of life, particularly in breastfed infants (Anzman-Frasca, Liu et al. 2013, Paul, Williams et al. 2014, Paul, Savage et al. 2016, Savage, Birch et al. 2016). Visual obscuring of cues mean that crying is one of the few behaviours a swaddled infant can adopt to demonstrate their hunger. However, swaddled infants cry less overall (Campos 1989, van Sleuwen, L'Hoir M et al. 2006, Caiola 2007, Karp 2007, Akhnikh, Engelberts et al. 2014, Edraki, Paran et al. 2014). These dual factors mean that swaddled infants are doubly disadvantaged in the feeding context. The situation is worsened moreover when the mother does not unswaddle the infant for feeding, which may reduce feed efficiency as discussed below.

A reduction in feed frequency is likely problematic, particularly for breastfed infants. As breastmilk is significantly easier to digest than formula milk, it is digested quicker (Madigan Army Medical Center 1989, Newton 2004, Wiessinger, West et al. 2010, Good 2020). This often means that breastfed infants require more frequent feeding than formula fed infants. During breastfeeding, the hormone prolactin acts on the milk-making tissues and the hormone oxytocin causes the breast to push out or 'let down' the milk. A hormonal surge is experienced with every feed. Around forty-five minutes after feeding, the surge declines. Repeated feeding therefore maintains circulating blood hormone levels, protecting a robust milk supply (Tennekoon, Arulambalam et al. 1994, Woolridge 1995, Neville 2001).

It is possible that feed efficiency is reduced under swaddled conditions. As swaddled infants cannot engage in active feeding behaviour, the intervention may be said to cultivate a distal ecology more symbolic of bottle-feeding patterns. Relative to breastfeeding, bottle-fed infants play a passive role in the feeding exchange, find it harder to regulate their intake, and experience fewer feeding bouts (Crow, Fawcett et al. 1980, Ventura and Mennella 2017). In this vein, “ineffective and passive feeding efforts” on the part of suckling infants has been associated with poor breastfeeding outcomes (Tow and Vallone 2009)(p629). The infant hands, which are anchored away during swaddling, ordinarily serve important roles in the breastfeeding process. Having free use of their hands encourages infants to latch-on to the breast (National Childbirth Trust 2015). Moreover, during feeds infants perform instinctive patterns of 'kneading' hand movements that increase maternal oxytocin levels and facilitate milk let-down (Matthiesen, Ransjo-Arvidson et al. 2001). In fact, data suggest that sucking and grasping are reciprocal (Buka and Lipsitt 1991), implying that interference with an infant’s grasping capabilities may impact their sucking efficiency. The biobehavioural link between sucking and grasping is reflected in neonatal reflexes, with sucking increasing strength and duration of the palmar grasp (Pollack 1960, Brown and Fredrickson 1977).

The hands also play an important role in sleep state organisation, a factor related to feeding. As infants progress from deep to light sleep, their arms begin to wave, or 'cycle' (Gerard, Harris et al. 2002, Richardson, Walker et al. 2010). Some believe this arm movement serves as a natural cue to help wake the infant for feeding (Fauntleroy 2012). Therefore, when the arms are bound by swaddling, the infant may cycle back into a quiet sleep and miss a feeding opportunity.

In sum, the feeding patterns observed during swaddling in this groups of dyads were more reflective of bottle-feeding than breastfeeding. This finding is problematic given that feed frequency and duration modulate human milk supply.

Ecological Validity

> *"As long as we design experiments in ways that respect the mutuality of the organism-environment relation and replicate the dynamic, real-world nature of the perceptual environment, we should be able to generalize to the real world"*
>
> (Lewkowicz 2001)(p438).

In this quote, Lewkowicz highlighted the influential nature of environment in provoking certain actions through the information or cues that it provides. For instance, Western industrialised home environments are typically equipped with bathing facilities, cooking facilities and leisure facilities - instruments that facilitate a Western routine. To represent the participants' naturalistic environment as far as possible, careful attention was made in this study to include these features within the lab environment. These naturalistic features provided an ‘illusion of familiarity’ (Brannigan and Zwerman 2001). In this context, the methodology was more able to identify the critical dimensions of swaddling (as distinct from other stimuli) that led to changes in the phenomena of interest - sleep and feeding behaviours.

The degree to which the behavioural outcomes of the study can be generalised to participants' home environments is influenced by 'the Hawthorn effect'. This phenomenon refers to "a situation in which the introduction of experimental conditions designed to identify salient aspects of behaviour has the consequence of changing the behaviour it is designed to identify" (Brannigan and Zwerman 2001)(p56). One salient aspect of behaviour important to the present study - maternal responsiveness - is highly vulnerable to the hawthorn effect. People are shown to "put their best foot forward to show themselves in a more positive light" when they know they are being watched and more likely to weather any tribulations "with personal grace and dignity" (Brannigan and Zwerman 2001) (p56).

Although there are no objective criteria from which to measure ecological validity, one question is illuminative: To what degree does the environment (as distinct from swaddling) influence the phenomena of interest? When previously recorded in a lab environment, infant sleep state data has not demonstrated a first night effect (Mosko, McKenna et al. 1993). Nonetheless, whilst sleep and feeding behaviours are naturalistic and dynamic events, they cannot be considered outside of the environment in which they occur. Usual bedtime rituals and the familiar home sleeping environment serve as powerful conditioned cues. In credence to this fact, the present study adopted an approach to ecological validity that was guided by the specific study hypotheses and level of analysis. In this sense, the study environment contained the critical cues normally featuring in the home environment, and those cues were functionally meaningful to the area of enquiry - sleep and feeding behaviour.

Strengths and Limitations

As with any small study, the outcomes observed in this project cannot be assumed to imply causation or predictive value. There are numerous strengths and limitations that will be enumerated below:

1. Sampling and recruitment: The participants of this study comprised a convenience sample generated via social media and word of mouth. Scholars have deemed social media to provide a reasonable "high-quality alternative" to a representative sample, given the diversity of the potential population of respondents (Kosinski, Matz et al. 2015)(p545). Nonetheless, as the sample was restricted to breastfeeding mothers, participants were more likely to be older, more educated, and have a higher income than the general population (Little, Legare et al. 2018). Low-income, minority adults are known to face significant barriers to sleep research participation (Yu, Gumport et al. 2020), which may explain their under-representation in my project. It is therefore unclear whether these findings would be reflected in mothers at large. Furthermore, by using a convenience sample, the participant pool may not have been representative of the larger population. This can result from self-selection bias, where individuals who agree to participate in a study are more motivated than the general population. The demographic characteristics of these individuals may differ from the that of the target population (Topolovec-Vranic and Natarajan 2016).

2. Data capture: Further problems may occur when participants themselves are the primary means of data collection. Some swaddle studies have relied upon maternal reports (McRury 2010, Kelmanson 2013), yet this approach is an unreliable indicator of actual total sleep time, night-wake frequency and duration when validated against overnight infra-red video recordings and actigraphy (Sadeh 1994, Acebo, Sadeh et al. 2005, Asaka and Takada 2011, Simard, Bernier et al. 2013). By conducting the present project in a laboratory, the same standardised environment in as closed a system as possible was provided for each participant. This is thought to strengthen internal validity over a home setting, as the latter comprises open and complex systems (Greener 2011). Although the novelty of the lab environment and the presence of videosomnography equipment (sensors, leads, straps, etc) may raise issues of ecological validity, satisfaction of ecological validity is arguably not the primary purpose of experimental work. Rather, experimentation in itself illuminates sleep and feeding behaviour and enables the testing of hypotheses. This is intrinsically sufficient as an ultimate goal (Mook 1983, Lewkowicz 2001).

3. Study design: To delimit the degree to which data might be confounded by the residual effects of laboratory adaptation, reduce carryover effect and rule out allocation bias, participants' starting conditions were randomised in the present study. Further, the lab was crafted to contain the critical cues normally contained in the Western home environment (kitchen, bassinet, sofa, bathroom), and those cues were functionally meaningful to the area of enquiry - sleep and feeding behaviour.

4. Bias-reduction: Careful attention to ecological robustness was paired with several methodological strengths. Firstly, each study night was consecutive, therefore minimising the impact of any within-infant developmental changes. Further, the subjects served as their own controls so that the same dyad was tested under both experimental (swaddled) and control (non-swaddled) conditions on separate nights, thus boosting internal validity. Moreover, convergent validity was increased through the use of several data collection methods in combination.

5. Addressing knowledge-deficits: The interaction between interventions and sleep states is a largely neglected but important area in the study of infant sleep and arousal. "The difference in the physiologic effect of swaddling in QS and AS sleep" (van Sleuwen, Engelberts et al. 2007)(p1100) was identified in two systematic as requiring more research (van Sleuwen, Engelberts et al. 2007, Dixley 2015). Yet only five swaddle studies have differentiated between AS and QS, each containing substantial methodological limitations. The most common concerns involved the failure of studies to distinguish between naive and routinely swaddled infants (Brackbill 1973, Gerard, Harris et al. 2002, Franco, Seret et al. 2005, Meyer and Erler 2011), the failure to employ each infant as their own control (Richardson, Walker et al. 2010, Meyer and Erler 2011), and the failure to ascertain feeding mode (Brackbill 1973, Gerard, Harris et al. 2002, Franco, Seret et al. 2005, Meyer and Erler 2011). This project is therefore the first known swaddle study to address each of these problematic areas by focusing specifically on exclusively breastfeeding infants naïve to swaddling. In finding a significant difference between QS and AS under swaddled conditions, and offering several hypotheses

to explain the distinction, this work has shed light on a research gap that has remained chronic for over two decades.

The project is also the first known study to explore the interrelationship between swaddling and feeding. The only previous swaddle study to identify feeding method (Richardson, Walker et al. 2010) did not distinguish between exclusively breastfed infants and those breastfed in conjunction with formula feeding and/or solid food; and also did not explore how swaddling impacted upon feeding. In focusing on exclusively breastfed infants, the present study produced much-needed insight into the behaviour of this under-researched group. This methodological decision also strengthened the internal validity of the study relative to previous studies by delimiting feeding method as a confounding variable. Studies that examine infant sleep based on the feeding method have been complicated by dyads that stop exclusively breastfeeding during data collection (Hall, Clauson et al. 2006).

Moreover, this is the first known study to explore the interplay between swaddling and maternal-infant sleep interaction and sleep orientation. The bulk of studies investigating swaddling have focused on the experience and perceptions of either infant or mother. Conversely, by investigating the dyad, this work has brought a fresh, integrative understanding to the field. In contrast to the dogma of the dominant psychological model of infant sleep, this study acknowledged and gave credence to the fact that the infant cannot be separated from its position within the dyad (McKenna 2004).

6. Swaddle technique. Recall that many studies omit to describe swaddle technique in sufficient detail to enable a robust synthesis across the knowledgebase (Narangerel, Pollock et al. 2007, McRury 2010, Kelmanson 2013). To delimit the practical and safety issues associated with traditional blanket wraps, the project used a zip-up swaddle pod, similar to those adopted previously (Gerard, Harris et al. 2002). The pod is commercially available and therefore identical to those used by the general population, a hallmark of external validity. It is however unclear whether the observed trends may be generalised reliably to other brands of swaddle. One important aspect of swaddle technique that was not controlled for in this experiment was tightness. Lack of tightness measurement/standardization across studies is a longstanding methodological deficit across this field of research.

Suggestions for Further Research

The interrelationship between swaddling and feeding, particularly breastfeeding, is a grossly under-researched topic. There are many reasons, as detailed in the literature review, why swaddling may undermine breastfeeding and the present data strengthened those concerns. The topic therefore requires large-scale randomized evidence, preferably conducted nocturnally using objective methodology, for instance video-recordings. More research is needed to investigate the qualitative biological nature of sleep state shifts. The increase in AS observed in the present study, and in previous research, suggest that swaddling may activate the sympathetic nervous system. Yet the integrative function of the SNS and PNS and its role in infant bio-behaviour are under-researched (Oosterman and Schuengel 2007, Oosterman and Schuengel 2008, Alkon, Boyce et al. 2011, Bush, Caron et al. 2016). Future studies could use HRV analysis to measure nervous system responses to swaddling and any associated autonomic impairment (Ahmad, Tejuja et al. 2009, Oliveira, Martins et al. 2019). Alongside HRV, changes in digestion are another physiological indicator of sympathetic activation. These occur due to a diversion of blood flow away from the gastro-intestinal tract and an associated inhibition of peristalsis (the wave-like muscle contractions that move food). Biosensory studies have shown a link between tightness of material against the abdomen and digestive disturbance (Sone, Kato et al. 2000, Takasu, Tsukamoto et al. 2001). Further research is therefore needed to explore the digestive impact of swaddling.

The finding that swaddling was associated with a significantly reduced number of sleep changes could have implications for our understanding of SIDS as it implies problems with homeostasis and adaptability (Berntson, Bigger et al. 1997). It is uncertain how long the effects found in present and previous studies would endure if swaddling were to continue over a period of days or weeks. In this vein, studies of longer duration are required to investigate the process of habituation. Researchers could also explore to what extent solitary sleeping mitigates or exacerbates the effects of swaddling on state shifts and adaptability. Given that swaddling is typically used during the critical window of time in which infants are most vulnerable to SIDS, namely < 6 months of age (Ariagno and Giotzbech 1981, Byard and Krous 2001), and solitary sleeping is a risk factor for SIDS (BASIS 2020), such enquiry is urgently recommended.

Two systematic reviews on the topic of swaddling have highlighted the chronic failure of researchers to measure and calibrate swaddle tightness (van Sleuwen, Engelberts et al. 2007, Dixley 2015). Despite the potential importance of swaddle tightness, the variable remains challenging to operationalise.

Overall, more research on the interconnections between macro-analytical concepts in swaddle research (such as feeding and sleep state) and micro-analytical processes (e.g., respiration, heart rate, tightness) is desirable, as the resulting data may not align with conventional assumptions.

Conclusion

The evidence from both the behavioural and biological data obtained in this sample of dyads strongly support the view that swaddling shapes both infant and maternal outcomes. As a deviation in sleep ecology, swaddling has consequences for the functioning of infant sleep state and maternal lactation in a similar vein to solitary sleep. If replicated in future studies, the trends discussed could challenge some of the assumptions about the impact of swaddling that have emerged from studies of formula fed and habituated infants. For instance, if breastfed infants indeed experience more active sleep while swaddled, then the conclusion that swaddling lengthens quiet sleep may be more a product of artificial milk consumption and not an accurate representation of a typical neonatal response. This has possible implications for infant well-being as active sleep is associated with developmental regression, given its predominance in very young infants.

Chapter 8. Pressure sensor: a new innovation to calibrate swaddle tightness

> *"Sometimes people assume their baby doesn't like being swaddled, mainly because their baby wiggles or cries while they're being put in a swaddle, but more often than not, this is simply because the swaddle isn't tight enough"*
> *(Ones 2020).*

Background

The thesis now turns to the practical application of swaddling. This project examined the feasibility of an innovative device to calibrate the application of swaddle tightness upon healthy newborn term infants < 4 months of age.

Swaddling is an infant-care practice in which a piece of material is wrapped firmly around an infant's body to restrain limb movement and thereby pacify the infant. One advantage of swaddling is its versatility; a swaddle can be applied in a number of techniques that range from loose wrapping to tight binding. Aside from domestic contexts, swaddling is also applied in medical settings. Neonatal clinicians use the intervention as a method of pain relief, to promote sleep, and as a means of motor restraint to facilitate medical procedures (Dezhdar, Jahanpour et al. 2016). The widespread prevalence of swaddling across settings makes it a fertile topic for scientific exploration. In 2019 The Lullaby Trust cited swaddling at the top of their list of factors in need of further research (The Lullaby Trust 2019).

When attempting to measure tightness, previous studies have failed to appreciate the physics of swaddling. During use, a swaddle interacts with the infant body dynamically and continuously. In this context, pressure is effected by the size of the infant, the type of swaddle material[16] and the position of the infant (Seo, Kim et al.). In an effort to control for such factors, the present study adopted specific protocol.

The importance of swaddle tightness

[16] The ability of the material to follow bodily movement can cause readings to fluctuate Makabe, H., H. Momota, T. Mitsuno and K. Ueda (1993). "Effect of covered area at the waist on clothing pressure." Sen'i Gakkaishi **49**(10): 513-521..

In a systematic review of swaddle studies (Dixley 2015), no study attempted to measure tightness, thus highlighting the need for a reliable tightness-calibration instrument. Certainly, the relative tightness of a swaddle impacts many aspects of infant functioning, both physical and mental.

Swaddle tightness and the calming effect

The American Academy of Pediatrics Task Force on Sudden Infant Death Syndrome suggest that the calming effects of swaddling are directly related to swaddle 'tightness'. This view is shared by clinicians whom argue that swaddling's sedative effects are "triggered by very specific stimuli delivered above a certain threshold" (Karp 2012)(p67). Paediatrician Karp maintains the view that the tighter the swaddle, the calmer the baby (Karp 2002), asserting that "loose swaddling will actually make fussy babies more upset" (Karp 2004) (p103). Indeed, in the neonatal setting, there is evidence to suggest that infants, particularly those born prematurely, prefer stronger pressure when touched (Field 2000) and experience light pressure as unpleasant (Field 1995). As examined in the literature review, this sentiment is echoed in other sources of parenting advice across cultures.

Swaddle tightness and infant feeding

Degree of swaddle tightness is also believed to be a key mechanic in feeding behaviour. Some clinicians believe feeding is enhanced by swaddling because the deep pressure swaddling provides assists infants in organizing sensory input (Fischel 1982, Weiss-Salinas and Williams 2001). Others argue that tight swaddling is a hindrance to feeding for several reasons[17]. Firstly, tight swaddling prohibits the use of infant posture to elicit feeding cues. Early hunger cues include mouthing hands or objects, making sucking noises or motions, clenching fingers or fists over the torso, flexing arms and legs, or engaging the rooting reflex. Secondly, for breastfeeding mothers, tight swaddling negatively interferes with the ability to adopt optimum positioning (Charlmers 2005). Thirdly, the continuous sensory load of tight swaddling may be problematic for infants described as highly sensitive to touch; the gag reflex of such infants can be triggered by pressure applied to non-oral body parts, such as the arm or shoulder (Scarborough, Boyce et al. 2006), locations typically stimulated via swaddling. Fourthly, lactation specialists maintain that breastfed infants should not have their hands anchored away from the breast by swaddling (Cadwell 2007). Infants use their hands as well as their mouths to stimulate their mother's breast thus increasing maternal oxytocin levels (Matthiesen, Ransjo-Arvidson et al. 2001). Finally, it is possible for an infant to be so tightly swaddled that they have inadequate neck flexion to facilitate the suck/swallow/breathe sequence necessary for nursing (Boles 2017).

Despite these arguments, the exact mechanisms influencing the relationship between feeding and swaddle tightness have yet to be determined. The field of biosensory mechanics suggests that pressure applied to the body can influence the digestive system and nervous systems in certain ways. For instance, tightness around the torso has been shown to decrease saliva

[17] For more detail, see the Biobehavioural Review, [Chapter number].

production (Okura, Midorikawa-Tsurutani et al. 2000). In a similar vein, clothing skin pressure has an inhibitory effect on the absorption of dietary carbohydrate in the small intestine (Sone, Kato et al. 2000) and increases energy expenditure by increasing the energy cost of movement (Apurba and Alagirusamy 2010, Na 2015). The degree of pressure at which such effects can be observed in infants remains to be determined.

Swaddle tightness and temperature regulation

Numerous studies have associated swaddling with temperature regulation, albeit with conflicting results. Bystrova et al observed that tightly swaddled infants experience a delay in temperature elevation during the newborn period (Bystrova, Widstrom et al. 2003). Conversely, the American Academy of Pediatrics warn that tight swaddling can lead to life-threatening hyperthermia when combined with ‘excessive bundling’ (Gilbert, Rudd et al. 1992, American Academy of Pediatrics Task Force on Sudden Infant Death Syndrome 2000).

It is possible that motor restraint poses a behavioural hurdle to effective temperature regulation. Infants do not regulate their body temperature by shivering, for instance. Rather, they adopt postures to cool down or warm up. Cold infants tend to be more wakeful and active, moving their limbs, whereas hot infants have been observed to adopt a 'starfish' position by extending the arms and legs (Harpin, Chellappah et al. 1983, Ammari, Schulze et al. 2009). Tight swaddling prevents such postural strategizing.

Swaddle tightness and cardiorespiratory function

There is also evidence to suggest that swaddling may impair cardiorespiratory function. In the case of swaddles which are too loose, there is a risk of inadvertent head covering (Fleming, Gilbert et al. 1990, Fleming, Azaz et al. 1992, Blair, Mitchell et al. 2008). On the other hand, swaddles that are too tight reduce infant heart rate (Gerard, Harris et al. 2002). Indeed, the swaddling technique used in one study (Bystrova, Matthiesen et al. 2007) was so tight that some of the infants’ feet became colder from reduced blood flow.

As swaddle tightness has been shown to increase thoracic compression exponentially (Kahn, Groswasser et al. 1992, Meyer and Erler 2011), respiratory rate follows ($P <.05$)(Gerard, Harris et al. 2002). This finding not only predicts acute respiratory infection (ARI), which is more common in swaddled infants (Yurdakok, Yavuz et al. 1990, van Sleuwen, Engelberts et al. 2007), but also has implications for Sudden Infant Death Syndrome (SIDS). Such abnormalities in cardiorespiratory function have been shown to dampen the arousal response during sleep, needed to regulate breathing (Harper, Leake et al. 1981, Kinney, Filiano et al. 1995, Byard and Krous 2001, Harper and Kinney 2010). The decreased arousability shown by swaddled infants is unlikely to be explained by the material’s constant stimulation of the skin and thermal receptors, as a 2010 study (Richardson, Walker et al. 2010) controlled for these factors and still found decreased arousability in swaddled infants. Rather, the thoracic compression resulting from tight swaddling may lead to a reduction in oxygen saturation and a consequent increase in respiratory rate and cardiac activity (Meyer and Erler 2011). Similarly, adult studies show that pressure from material is associated with a drop in heart rate by 15–20 % (Na 2015).

In a similar vein, tightness has also been shown to influence infant blood pressure (American Academy of Pediatrics Task Force on Sudden Infant Death Syndrome 2000), negatively impacting Heart Rate Variation (HRV) (Schechtman, Harper et al. 1989), a factor implicated in SIDS (Matthews 1984, Kelly, Golub et al. 1986, Schechtman, Harper et al. 1988). Eckehard and Meyer (2011) studied this phenomenon and found a correlation between swaddle tightness and HRV, an effect they associated with laboured breathing:

> *"The effect of swaddling tightness is under discussion: thoracic compression is intensified with swaddling. As a result, the depth of breathing is restricted. This leads to a reduction in ventilation and oxygen concentration in the blood. As a form of compensation, this causes increased respiratory activity and involuntarily stimulates the cardiac activity"*
> *(Meyer and Erler 2011)(p155).*

Swaddle tightness and cognition

Cognition is perhaps the least investigated variable in swaddling research. In biosensory studies of adults, the restriction of muscle movement and the application of pressure provided by tightness has been shown to influence kinesthetic perception (Li and Wong). Other biosensory studies highlight an increase in fabric pressure against the skin tends to produce stronger sensations of 'roughness' (Sukigara and Ishibashi 1994). More generally, the intensity of a tactile experience has been shown to affect the responsiveness and firing patterns of cortical cells (Burton 1996, Kandel, Schwartz et al. 2000). As detailed in the biobehavioural review, a small pool of evidence suggests that tight swaddling may enhance the intake of new information by concentrating attentive resources (Gardner and Turkewitz 1982, Gardner, Karmel et al. 1992, Lester, Boukydis et al. 1996, Lejeune, Delacroix et al. 2021). Further research is needed to investigate the cognitive impact of swaddling, particularly during such a neurodevelopmentally sensitive period of life.

Swaddle tightness and hip dysplasia

As detailed in the biobehavioural review, it is widely acknowledged that developmental dysplasia of the hip (DDH) may occur if swaddling is too tight, especially if the baby is swaddled with straightened legs (Mahan and Kasser 2008, Chisholm and Cary 2009). Cultures that adopt swaddle techniques that are tight around the hips, such as Turkey, Saudi Arabia and Japan, have an increased prevalence of DDH (Ishida 1977, Shaheen 1989, Kutlu, Memik et al. 1992, Akman, Korkmaz et al. 2007, Dogruel, Atalar et al. 2008, Guner, Guner et al. 2013). The American Academy of Paediatrics assert that swaddling should "allow room for movement around the hips and knees" (Task Force On Sudden Infant Death 2016)(p7). The American Academy of Orthopaedic Surgeons and International Hip Dysplasia Institute (IHDI 2020) reiterate that parents who want to swaddle should practice "hip-healthy swaddling", a technique that allows the infant's legs "to bend up and out at the hips" and not "tightly wrapped straight down and pressed together" (IHDI 2020). Certainly, overly-tight swaddling limits hip flexion/abduction and can even dislocated unstable hips (Harcke, Karatas et al.

2016). Despite a large body of research, no objective measurement of tightness has been used.

The problem: lack of an objective method to measure swaddle tightness

Despite the importance of swaddle tightness, the variable remains challenging to operationalise. A 2017 review of swaddle research concluded: "Some of the most serious potential risks of swaddling such as an increased rate of ARI and DDH seem to only be associated with tight swaddling; However, the degree of tightness that puts infants at risk is uncertain" (Nelson 2017)(p222).

Parents, researchers, policy makers and health professionals are limited to describing swaddle tightness in subjective terms. Even the most detailed guidelines that attempt to outline this issue, SIDS and Kids National Scientific Advisory Group vaguely advise that swaddles "should not be too tight and must allow for hip and chest wall movement" (SIDS and Kids National Scientific Advisory Group (NSAG) 2009)(p2). The failure to measure swaddle tightness and discrepancy in understanding the variable is further reflected in scholarly recommendations. Although some academics recommend that infants be "loosely swaddled" (Fischel 1982)(p58), others suggest infants should be swaddled "snugly" (Task Force On Sudden Infant Death 2016, Alosaimi, Kaneetah et al. 2020)(p7) or "moderately snug" (White, Carrara et al. 2012). The American Academy of Pediatrics recognise the possibility of swaddling infants too loosely, risking asphyxiation or strangulation (Moon and Task Force On Sudden Infant Death 2016). In an attempt to alleviate this issue and provide objective measurement, they advise parents that "You want to be able to get at least two or three fingers between the baby's chest and the swaddle" (American Academy of Pediatrics 2013).

The vagueness of guidelines is compounded by discrepancy amongst lay and professional conceptions as to precisely the optimum 'zone' of tightness. Owing to a lack of precise measurement, this variable is inherently subjective, and understandings are shown to vary widely (Mrayan, Abujilban et al. 2018). From some health professionals, "firm pressure" is advised. Others advocate wrapping the swaddle "snugly" (Weiss-Salinas and Williams 2001, Karp 2020) whilst those more critical of swaddling warn that swaddles should be wrapped "not too tightly" (Mates 1980)(p52). Others call for a "gentle, contained pressure similar to what might be experienced in a gentle embrace or the conditions of being in the womb" (Boles 2017).

Lay discourse is similarly lacking in precision. A 2015 focus group study of mothers (Dixley 2015), revealed a common narrative involving the use of infant movement to measure tightness. Most participants (around two thirds) deemed swaddles to be sufficiently tight when all infant movement was prohibited. Although motor restraint is a baseline dynamic of swaddling, such a subjective technique of tightness measurement increases risk of excessive tightness.

Recognising the plight of parents, Thach, in his report on swaddling and SIDS, asserted that "caretakers need some simple method to determine pressure in swaddled infants" (Thach

2009)(p461). Parents turn to health professionals as a primary source of such advice (Appleton, Laws et al. 2018, Garg, Eastwood et al. 2018, Lobo S, Lucas CJ et al. 2019), however lack of objective guidelines frustrate attempts of health professionals to provide guidance. 62.2 per cent of the respondents in the aforementioned health professionals survey admitted they did not know how to measure swaddle tightness (see Chapter 9).

In the research field, such subjective and vague notions dominate the discourse of tightness, making quantitative study unfeasible and qualitative study unreliable. Without calibration of swaddle tightness, studies inadvertently introduce tightness as a confounding variable. This problem also undermines the ability to conduct comparison between studies. A recent meta-analysis combining data from observational studies of swaddling found a high degree of variability between studies (Pease, Fleming et al. 2016). When the intervention of swaddling is operationalised by individual researchers, not only is there limited comparability of findings among research teams but the data are also compromised by measurement error. This problem was highlighted by Anders in 1974 (Anders 1974). He pointed out that uniform methodologies which can be readily shared amongst research teams and that permit multiple data collection attempts are essential requirements for the clinical acceptability of interventions such as swaddling. Later, in 1982, Fischel observed that tight swaddling may favour certain infant behaviours (sucking) over others (limb movement):

> *"The tightness of swaddle chosen by different researchers might influence the range and intensity of responses available to the baby, and might further influence the probability of responding in one or another modality. If the child is tightly swaddled, the probability of "doing something" on the sucking stimulus may increase. If the child is loosely or not swaddled, body movement may become a more likely response dimension" (Fischel 1982)(p58).*

However, decades later, this issue remains unresolved. Lack of standardization across studies continues to pose a methodological constraint in swaddle research. A systematic review on the topic of swaddling carried out in 2007, and another carried out in 2015, highlighted the chronic failure of researchers to measure and calibrate swaddle tightness (van Sleuwen, Engelberts et al. 2007, Dixley 2015). Indeed, lack of a sufficiently precise record of swaddling technique was considered the largest threat to data robustness (Dixley 2015). Inconsistency in tightness may thus explain the resulting discrepancy in findings across studies; most noticeably varying respiratory rates. In this vein, failing to quantify swaddle tightness not only jeopardises the reliability of individual research data, but also prevents robust synthesis of data across studies.

Previous attempts to solve the problem

To date, attempts at tightness calibration have been rudimentary. The most common lay method for gauging degree of tightness is to insert two fingers between the swaddle and the infant as described above. In advising parents, Karp suggested a variation on this technique using the whole hand:

"Slide your hand between the blanket and your baby's chest. It should feel as snug as your hand slid between your pregnant belly and the elastic waistband of your pants at the end of your ninth month"(Karp 2004)(p107).

Using fingers or a hand as a measuring device is not only idiosyncratic but also unreplaceable and unquantifiable. Such factors are of particular import within a research context.

Although most researchers fail to calibrate swaddle tightness, a handful have attempted to do so. As recently as 2018, Fletcher and Pham sought to evaluate the variability in swaddling tightness applied in an American newborn nursery and neonatal intensive care unit (Fletcher, Pham et al. 2018). After acknowledging the unsatisfactory nature of the finger method, the researchers attempted to measure tightness more objectively using a tongue depressor:

"Guidelines for swaddling recommend the ability to fit "2 or 3 fingers" between the child and the wrap. Because this measure depends on the researcher performing the observation, the tightness of the wrap was assessed using a standard 1-in wide tongue depressor. Researchers recorded on the observation sheet whether a tongue depressor was able to fit between the child and the wrap" (Fletcher, Pham et al. 2018)(p304).

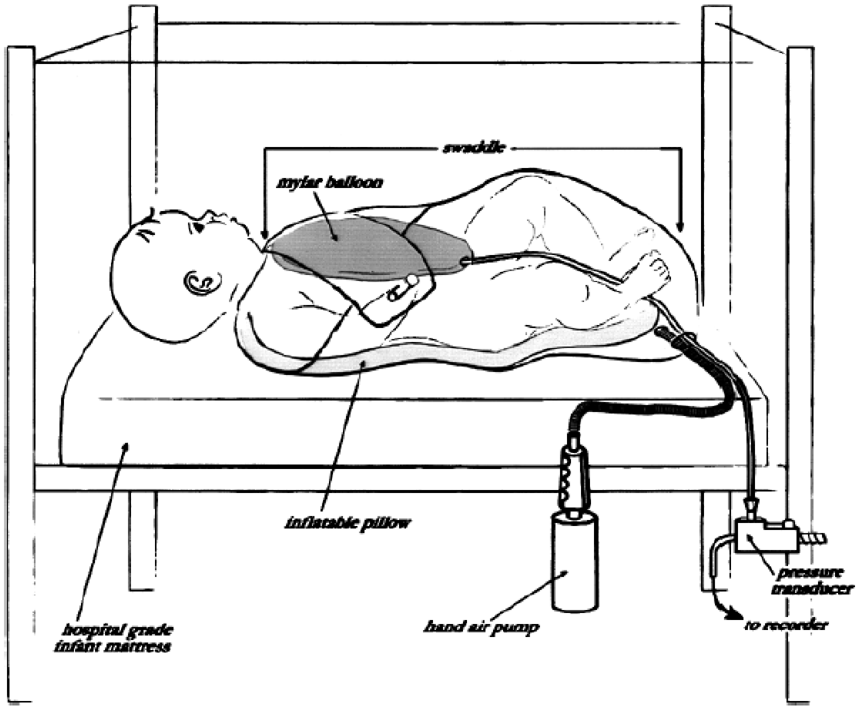
The authors did not specify the location on the infant's body where the measurement was taken. Further, although the tongue depressor method may be more standardised than the traditional two fingers method, it cannot account for individual differences in infant size. Moreover, the tongue depressor method is limited as it can only produce dichotomous data: "tight" or "not tight". It therefore fails to measure the most elusive and arguably most important of variables: 'degree' of tightness.

Previous attempts at measuring degree of tightness were made in the medical research of the 1960s and 1970s. To facilitate sleep and minimize movement artifacts, several researchers 'swaddled' infants in vacuum splints. These devices consisted of an air-tight chambered bag filled with either water or tiny polyester beads. The bag was wrapped around the infant's body and secured with belts. Tightness was then measured via air pressure (Williams, Schachter et al. 1967, Schachter, Williams et al. 1971, Lachin and Schachter 1974, Schachter, Kerr et al. 1975, Schachter, Kuller et al. 1979). A significant limitation of this approach was the requirement that the infant be calm prior to application. Another was the need for the infant to be precisely positioned and swaddled in a blanket prior to inflation (Golan, Marco et al. 2011). The unsatisfactory nature of this method led to a decline in its use. In 2008, the devices were re-termed "infant immobilizers" and their application restricted to brief medical procedures such as CT, MRI or bone scans (Mathur, Neil et al. 2008, Golan, Marco et al. 2011).

Perhaps the most ambitious attempt at measuring degree of swaddle tightness was that of Gerard and colleagues (2002). Their study sought to evaluate the respiratory effects of tightening a swaddle "from loose levels to higher levels" using a pressure transducer (Gerard, Harris et al. 2002). Principles of engineering illustrate why this approach was unsatisfactory:

When tightness is the variable of interest, what is being measured is the resulting effect of 'pressure' - an expression of force exerted on a surface per unit area. Gerard's experiment measured atmospheric pressure using a pressure transducer. This type of gauge reads zero at atmospheric pressure and positive when pressure is greater than atmospheric. As pressure transducers can only measure gases or liquids, Gerard and his team had to fashion an elaborate circuit containing a hand pump, plastic tubing, polyester balloon, inflatable pillow, swaddle and transducer device. The pillow was placed inside the swaddle along the infant's back and the balloon was placed within the swaddle on top of the infant's chest. The swaddle was then tightened by inflating the pillow with a hand air pump that was connected via plastic tubing. The balloon was used to measure the internal pressure of the swaddle.

Figure 36 Gerard, Harris et al. (2002) configuration



Gerard and colleagues used this arrangement to swaddle 5 infants with a swaddle technique they termed 'tight tuck' and 4 infants using a 'traditional style'. The team attempted to achieve a 'low-pressure goal' using the tight tuck technique and a 'higher pressure goal' using the traditional style. There were several limitations to their methodology. Firstly, swaddle technique was not alternated intra- subject, presumably because to do so would disrupt the delicate layout of apparatus. Secondly, the layout of apparatus limited findings to extra-thoracic pressure alone. Pressure points at other bodily locations of import (hips, for instance) could not be measured using this approach.

The solution? Tactile pressure sensor

The methodology proposed in the present project is unique in swaddle research. In contrast to Gerard and colleagues, this project used tactile sensing to acquire data. The most popular types of tactile sensor are resistive and capacitive (Patel 2015). Resistive tactile sensors comprise a flexible plate and a ridged plate. When a sufficient degree of mechanical pressure is applied, the flexible plate touches the ridged plate generating a measurement. This type of sensor has limited sensitivity, meaning that relatively more pressure is needed to activate it.

In contrasted this study used capacitive tactile sensors, a type of sensor commonly used to measure the interface pressure between soft objects (Ashruf 2002). Its output is generally less vulnerable to temperature and humidity and is three times more sensitive than resistive sensors; it is therefore able to detect the lightest of touches (Ashruf 2002). In contrast to resistive sensors, capacitive tactile sensors consist of two conductive plates which do not move. Instead, the plates are separated by a matrix of dielectric material. This material acts as an insulator detecting and measuring changes in capacitance. Therefore, whilst Gerard's methodology measured atmospheric pressure, the present study measured absolute pressure - the sum of gauge pressure and atmospheric pressure.

Study methods

Ethics Approval

Ethical approval was obtained from the Durham University Department of Anthropology Ethics and Data Protection Subcommittee. Informed parental consent was obtained before the study.

Participants

Participants were recruited at 'Mother & Baby groups' across the South Tyneside region in North East England. The project utilized opportunistic or 'convenience' sampling through the selection of 10 infants on a first-come basis within the predefined population. As a piece of exploratory research, the aim of the project was to test the feasibility of the sensor in a quick and relatively inexpensive way. Here, the infant body was the central characteristic of the sample studied and any selection of infant bodies < 4 months of age were likely to facilitate testing of the sensor. If the sensor were not to perform even in this biased sample, it would be unlikely to perform in a relatively unbiased sample.

Inclusion criteria required that participants were no older than 4 months of age at the time of the experiment, and in good health (understood as the absence of disease or disability).

These characteristics satisfy the sample as representing a 'typical case' (Etikan, Musa et al. 2016). The word typical does not imply that the sample is representative but rather that the sample enables a comparison with other samples of typical infants (i.e., comparing samples, not generalising a sample to a population).

Voluntary informed consent was obtained before enrolment in the study in accordance with the 'Declaration of Helsinki' (WMA 2013). Potential participants were provided with an information sheet (Appendix 5) and consent form (Appendix 6) and informed they may cease participation in the study at any time.

Study design

The project is an explorative, proof-of-concept study. A randomised cross-over design was employed where the subjects served as their own controls so that the same individual was randomly tested under both experimental (traditional wrap) and control (zip-up swaddle pod) conditions. Both items were purchased from retail outlets.

Figure 37 "Hana Swaddle Pod". Made from an organic cotton/bamboo blend.

Figure 38 Traditional swaddle wrap. Made from an organic cotton/bamboo blend

Hypothesis

This project aimed to examine whether a pressure sensor could enable a researcher to standardise the tightness of a traditional swaddle-wrap across numerous attempts. To act as a control condition, a zip-up swaddle-pod was also tested with the sensor. Unlike the wrap, the swaddle-pod could not be adjusted and therefore could not be calibrated. For this reason, it was proposed that under swaddle-wrap conditions there would be smaller fluctuations in measurement values[18]. The null hypothesis maintained that there would be no significant difference between pod and wrap conditions, with both being equally variable.

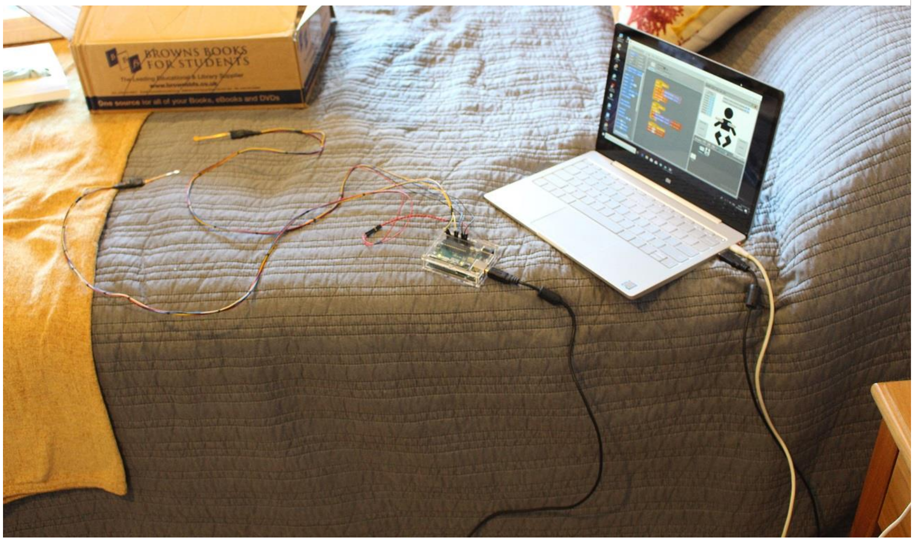
The sensor: technical specifications

This study used two capacitive 'miniature force sensors' which fed into a laptop containing software configured to register their readings of pressure (see Figure 40). The sensors were purchased from and pre-calibrated by the manufacturer Pressure Profile Systems Inc. The manufacturer has a comprehensive portfolio of sensors for use in research, design, and development processes. Variations of the sensor chosen for the present study have been used in numerous human-based applications including the measuring of headset comfort and fit, helmet pressure, and bra comfort and fit. Previously, a nappy manufacturer used the sensors to verify the fit of nappies.

With this type of sensor, measurements are reliable with less than 1% repeatability error. The voltage of the sensors is very low with a maximum of 5V, equivalent to a mobile phone. The current is 2.7mA, therefore maximum possible power is 13.5mW or 0.0135 W. The sensors themselves have an insulating layer of material so no electrical current can be delivered to the user, and that material is RoHS compliant[19].

[18] The sensor measured capacitance. This force is expressed as the ratio of the electric charge (Q) on each conductor to the potential difference (V) between them. The SI unit of capacitance is the farad (F), which is equal to one coulomb per volt (1 C/V).
[19] Full sensor specifications can be found of the Pressure Profile Systems Inc website https://pressureprofile.com/sensors/singletact

Figure 39 Sensor-to-laptop interface



Procedure

The experiment was conducted at the Mother and Baby group location upon a mat on the floor. The sensors were tested under two conditions: a) a commercially available zip-up swaddle pod and b) a traditional non-stretchy cloth wrap, both of which were purchased from retail outlets. Irrespective of infant age, small infants were given the '0-3 months' sized swaddle pod (measures 55cm from neckline to toes), whilst large infants were given the '3-6 months' sized swaddle pod (measures 65cm from neckline to toes). The same traditional cloth wrap was used with all infants. To eliminate order effects, the order of the pod/wrap condition for each infant was decided by coin toss. The tradition swaddle wrap was configured using the popular four-step DUDU method (Karp 2020).

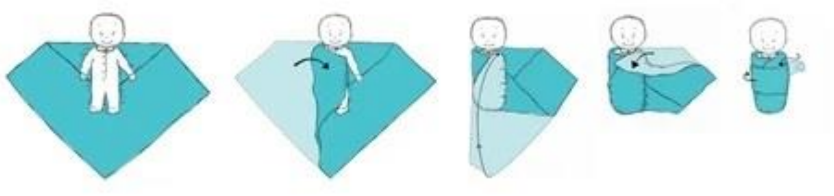


Figure 40 DUDU method (Karp 2020).

Upon completion of a consent form the infant was weighed wearing their own vest and sleepsuit. The weight measurement was taken using a calibrated electronic infant scale (Figure 42). The infant was then measured in length from head to foot whilst lying supine on an infant measuring mat (Figure 42). Next, the same swaddle wrap and the same swaddle pod style (0-3 / 4-6 months) were used on each infant. When using the wrap, the same swaddle technique was used on each infant. Each infant was placed in the same position (supine), under the same conditions (after a feed), wearing the same amount of clothing (vest and sleepsuit), in the same location (on the floor). To further reduce confounding, the same researcher applied the sensors and swaddle to each infant.

Figure 41 calibrated electronic infant scale and measuring mat

Next, the sensors were placed between the swaddle wrap/pod and the infant's clothing at two body points: at the halfway point of the humerus positioned at the front, and the top of the femur positioned at the front.

Figure 42 sensor applied under pod conditions

The researcher used the rudimentary software interface (Figure 44) to try and replicate pressure readings from one infant to next. To reduce measurement error, three repeated measurements were taken at each point. The swaddle was removed and refastened after each reading to assess consistency of readings. Each reading was measured in farads (F) and took approximately three seconds to generate. Next, the researcher repeated the exercise with the swaddle wrap/pod.

Figure 43 Software interface

Measurements were averaged for each infant. To determine whether the sensor was affected by infant size, infants were dichotomised into 'large' or 'small' using the World Health Organisation Child Growth Standards, using the 50th percentile in the distinguishing midpoint (Appendix 7).

Figure 44 Sensor applied under wrap conditions

Findings

10 babies were recruited and 10 were successfully measured in both conditions.

Table 16 Participant characteristics

Participant ID	Weight (Hobson, Pace-Schott et al. 2000)	Length (cm)
Inf1	8.4	66.7
Inf2	7.6	59.6
Inf3	7.2	62.3
Inf4	6.7	60.2
Inf5	5.4	56.8
Inf6	3.6	49.9
Inf7	4.7	55.4

Inf8	8.2	66.2
Inf9	3.6	51.7
Inf10	8.4	63.5

Figures 46 and 47 detail the mean pressure measurement (farads) for each infant group by body part for each swaddle condition. Error bars show standard deviation.

Figure 45 Humerus mean pressure

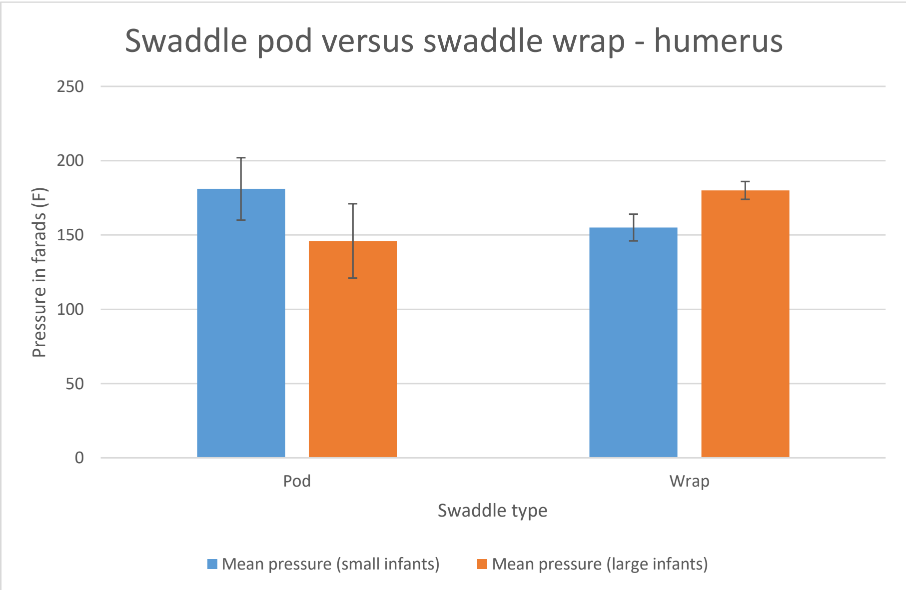
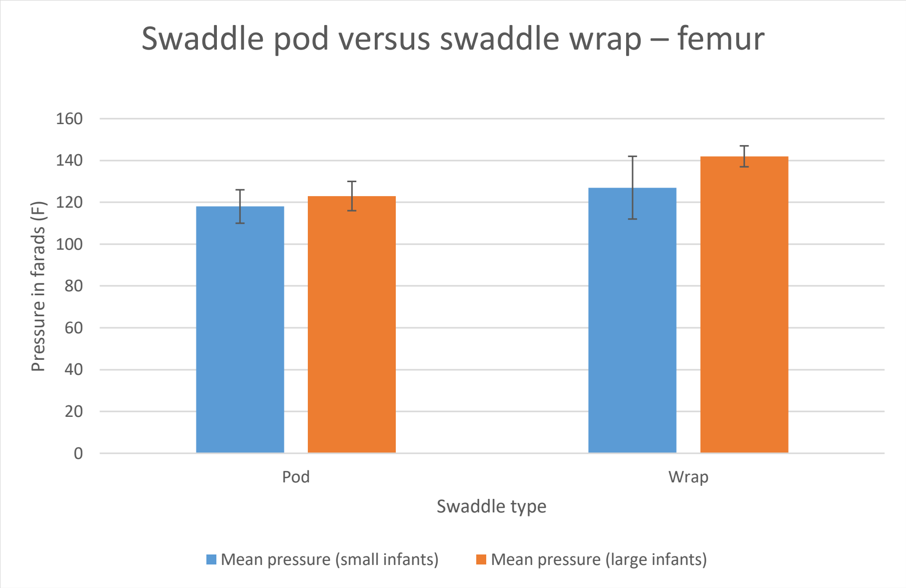


Figure 46 Femur mean pressure



Analysis

Data were tested for normality using the Kolmogorov-Smirnov and Shapiro-Wilk tests for normality (.05 alpha value).

Tables 17-20 detail the mean and standard deviation of the readings across infants at both body points (humerus and femur) to compare swaddle types (wrap and pod).

Table 17 Small infants – swaddle pod versus swaddle wrap - humerus

Descriptive Statistics

	N	Minimum	Maximum	Mean	Std. Deviation
Pod	6	152.00	210.00	181.2778	21.46151
Wrap	6	141.33	167.67	155.2222	9.28958

Table 18 Small infants – swaddle pod versus swaddle wrap – femur

Descriptive Statistics

	N	Minimum	Maximum	Mean	Std. Deviation
Wrap	6	102.67	144.33	126.6111	14.71268
Pod	6	107.33	127.67	117.8889	8.43186

Table 19 Large infants – swaddle pod versus swaddle wrap - humerus

Descriptive Statistics

	N	Minimum	Maximum	Mean	Std. Deviation
Wrap	4	172.33	186.67	180.4167	6.00231
Pod	4	146.00	203.00	178.5000	25.31944

Table 20 Large infants – swaddle pod versus swaddle wrap – femur

Descriptive Statistics

	N	Minimum	Maximum	Mean	Std. Deviation
Wrap	4	134.33	145.67	142.3333	5.36104
Pod	4	119.00	133.33	123.2500	6.75703

In statistical terms, the higher the precision of a measurement instrument, the smaller the variability (standard deviation) of the fluctuations in its readings. The above analysis suggest that the pressure values obtained were more reliable under wrap conditions than under pod conditions. Under wrap conditions, the researcher could reliably and systematically adjust tightness to replicate previous measurement values. The only exception was pressure at the femur in small infants. This measurement had a larger standard deviation under wrap conditions than pod conditions.

Paired samples t tests were conducted to investigate if the two swaddle types (pod v traditional wrap) were significantly different in pressure at humerus and at femur. Results for the humerus indicate no significant difference in pressure between the two swaddle types: t(Calkins and Hill 2007) = 1.858; p = .096. Results for the femur however, indicate a significant difference in pressure between the two swaddle types: t(Calkins and Hill 2007) = -3.251; p = .010. A negative t-value indicates a reversal in the directionality of the effect. In comparison to the humerus, the result indicates significantly less pressure on the femur.

Discussion

The aim of this project was to provide an evidence-based evaluation of a novel device intended to calibrate swaddle tightness. The findings were favourable. Using the software interface, the researcher was able to accurately replicate swaddle tightness across three distinct applications with each infant. The process was infant-friendly as readings were instantaneous and the small and thin nature of the sensor enabled it to be discretely applied and removed.

The sensor used in the present study is superior to methodology adopted by previous scholars as it enabled a larger range of infant body sites to be monitored. For instance, whilst Gerard and his team were only able to measure tightness of swaddling upon the chest, the sensor in the present study could be placed on any a location - in this case, the arms and hips. This positioning was important, as firstly, variety in swaddle styles involve various positioning of the arms, and secondly, swaddling of the hips has been linked to hip dysplasia (see Biobehavioural review). In this regard, the paired samples t-test indicated significantly less pressure on the hips than the arms between wrap versus pod, across the 10 infants. Such findings are promising in the context of risk prevention. Indeed, there are a wide range of swaddle products available on the market, with variances in stretch, weight, material type, shape, size and features. In this regard, the sensor has utility for measuring pressure differences across swaddle products at any point on the body. This enables products to be distinguished for different populations (e.g., low birth, premature, NICU patients, healthy term infants) and for different purposes (e.g., sensory stimulation, containment, positioning, pain relief).

Another strength of the present study was the size of the sensor. The size of any sensor affects its interaction with the subject. The sensor in the present study was significantly less invasive than methodologies used by previous scholars whilst retaining quantitative reliability. The small size of the sensing area enabled it to produce accurate measurements of local pressure. Further, as the sensor was designed to be used on "virtually any geometry" (Pressure Profile Systems 2019), the flexible design was ideal in shaping to the curvature of the infant body. In this regard, there are numerous possible avenues of application. For instance, in addition to research centring upon swaddling, a diverse range of disciplines including medicine and psychology apply swaddling as a methodological tool to delimit movement artifacts[20] (Golan, Marco et al. 2011, Reilly, Byrne et al. 2012, Mahmoudabadi, Moghadam et al. 2018). The sensor can be used in these contexts to ensure a pressure threshold adequate to immobilize the infant is maintained with regard to their individual body stature, whilst minimising risk of hip dysplasia.

Nonetheless, there was one anomaly in the data: pressure of the femur in small infants, which had a larger standard deviation under wrap conditions than pod conditions. This finding was peculiar in light of all others showing a smaller standard deviation under wrap conditions than pod conditions across both infant sizes. There is a possible explanation for such discrepancy. Young infants tend to adopt a ‘frog-like’ position with their legs; The researcher did not

[20] See Clinical Review.

straighten the infant's legs for swaddling as she was mindful of safety guidelines detailing that swaddling should "allow room for movement around the hips and knees" (Moon and Task Force On Sudden Infant Death 2016). Considering the measurement anomaly only appeared for infants of the small BMI group, and only for the hip region, it is possible that the wrap was oversized for these infants. Unlike the pod which had two size variations, the wrap did not. A smaller, 'snugger' wrap may produce more consistent results for this group of infants.

Limitations

Due to resource constraints, the present study adopted a relatively small, non-probability sample of 10 infants. Results therefore cannot confidently be interpreted as typical of the general population but may be illustrative of other similar samples.

A further limitation due to research constraints involved oscillation of the sensor readings. As the sensor was high resolution, it was capable of producing a high number of readings per second. In other words, the value on the display fluctuated on the least significant digit. This was an example of random error, common in digital balances and always present in any measurement. Indeed, in this context pressure can naturally fluctuate by 0.2-0.4 HZ due to infant respiration (Amano, Minakuchi et al. 1996) and the ability of the swaddle material to follow bodily movement (Makabe, Momota et al. 1993). For this reason, the researcher took a screenshot of each reading and recorded the figure in the screenshot. In further research, oscillation may be handled by selecting more advanced software that conducts automated reading and transcription of data.

Possible applications

Further investigations are needed to optimize the design and methodology of the pressure sensor. To fully utilise the benefits of a diverse measurement range, an adjustable swaddle is highly recommended. In their study, Gerard and colleagues developed a cotton Spandex swaddle that was made adjustable with Velcro to fit different-sized infants. The addition of Velcro reduced the occurrence of infants spontaneously breaking free of the swaddle. When used in conjunction with the pressure sensor, such a wrap would not only secure the swaddle to the desired degree of tightness, but also allow the swaddle to be adjusted to varying degrees of tightness within or across subjects.

Aside from being compatible with various wrap styles, the sensor used in the present study is fluid enough to integrate with a range of data collection devices. For instance, wireless Bluetooth electronics could be incorporated to minimise the use of wires (Pressure Profile Systems 2020); plethysmography could measure thoracic and abdominal respiratory movements at varying degrees of swaddle tightness. Additionally, the sensor could also be used in conjunction with a skin capsule to evaluate the effect of varying degrees of tightness upon perspiration (Ogawa, Asayama et al. 1979, Kraning and Sturgeon 1983) which could illuminate the link between swaddling and overheating (American Academy of Pediatrics Task Force on Sudden Infant Death Syndrome 2000, Nelson 2017).

Conclusion

This project has examined the feasibility of a pressure sensor device to calibrate the application of swaddle tightness upon healthy newborn term infants < 4 months of age. The results indicate a high degree of reliability under experimental (traditional swaddle wrap) conditions. Using the software interface, the researcher was able to accurately replicate swaddle tightness across three distinct applications with each infant. Given that standardization and comparability are the hallmarks of strong data, such device could enable consistent tightness between treatments, therefore increasing the validity of future data.

Chapter 9. Health professionals' knowledge and opinions of infant swaddling: a descriptive cross-sectional survey

Introduction

> *"It is important for health-care providers to be educated about how best to model recommended behaviours to parents… Health-care providers should be aware of the pros and cons of swaddling and share this knowledge with new families"*
> (Goodstein, Hauck et al. 2016).

In 2016, the American Academy of Paediatrics (AAP) Task Force on SIDS issued the quote above. Against this backdrop, I conducted a survey to explore UK health professionals' thoughts, beliefs and observations about swaddling using a 15-item online questionnaire. The present chapter follows the recommended format for reporting web-based surveys, the Checklist for Reporting Results of Internet E-Surveys (CHERRIES) (Eysenbach 2004).

Determining professionals' understandings of swaddling is important in the construction and dissemination of much needed guidelines. For parents, health professionals pose a primary source of infant-care advice (Appleton, Laws et al. 2018, Garg, Eastwood et al. 2018). The prominence of professionals in infant care began in early 20th century which saw the establishment of UK health visiting via the Notification of Births Act. This legislation, along with the conversion of midwifery to a trained occupation, invited the "medical gaze" into the homes of families (Wright 1987)(p109). Women were told they needed to follow the instruction of scientifically-informed medical experts and without this direction they were dangerous to their children's health (Apple 1995). This period saw a shift from maternal reliance on traditional advice networks, such as family and friends, to a growing appreciation and reliance on scientific advice, birthing a concept that has been termed 'scientific motherhood' (Apple 1995). In contemporary Western clinical practice, this dominant biomedical model continues to frame health professionals as fountains of authoritative knowledge (Tomori 2014). A recent American survey of 100 parents found that most preferred consulting health professionals for information regarding the risks and benefits of swaddling, rather than the internet (Yang, Ragen et al. 2018). Similarly, a survey of 103 African American parents of infants 0 to 3 months of age (Oden, Powell et al. 2012), found that most preferred to obtain swaddling advice from health professionals over any other source.

Present day healthcare is characterised by high variation in the swaddling methods applied by professionals (Fletcher, Pham et al. 2018). Further, a widespread discrepancy exists between those health professionals that recommend swaddling and those that oppose it (Young, Gore et al. 2013, Day 2015). In lieu of official swaddling guidelines, the practice is open to subjective interpretation. Discrepancy in the advice delivered by professionals can undermine the maternal-clinical relationship and lead to extensive yet elusive variation in risk (Ball 2002, Ball 2003, Ball and Russell 2012, Tully and Ball 2013, Volpe, Ball et al. 2013, Tully, Stuebe et al. 2017, Ball 2020, Ball, Taylor et al. 2020). To date, no explanation or theory has been advanced to explore variation in professional views.

Research has shown a similar diversity in swaddle technique across parents (Dixley 2015, Garg, Eastwood et al. 2018, Yang, Ragen et al. 2018). This is likely because the swaddle techniques and views they learn from health professionals are then adopted in the home (Von Kohorn, Corwin et al. 2010). Despite the crucial role health professionals play in disseminating swaddle knowledge, there remains a dearth of research exploring and systematising their views. To date there have been four studies of health professionals focusing on swaddling: a 2013 Australia-based paper survey of 161 child health nurses (Young, Gore et al. 2013) ('the Australian survey'), a 2018 America-based paper survey of 49 paediatricians (Yang, Ragen et al. 2018) ('the American survey'), a 2020 Saudi Arabia-based paper survey of 39 family physicians and 22 paediatricians (Alosaimi, Kaneetah et al. 2020)('the Arabian survey'), and a 2021 paper based Indian survey of 45 paediatricians and 219 nurses that focused on developmental dysplasia of the hip (Pinto, Aroojis et al. 2021)("The Indian Survey"). An additional study, a 2013 American study of neonatal nurses and therapists, did not focus on swaddling but did include one question on the topic (Zarem, Crapnell et al. 2013). Whilst these studies were methodologically robust, data were restricted to only a few occupation types and the survey items failed to explore important facets of swaddling practice such as sleep location and co-occurring interventions.

The present survey builds upon the existing knowledge-base via a contrasting recruitment strategy and a broader range of both dependent and independent variables. The main aim of the survey was to ascertain the knowledge and opinions of UK infant care professionals regarding swaddling. The secondary aim was to ascertain whether swaddling opinion differed according to occupation type and occupation length. The present study is the first UK-based swaddling survey of health professionals.

Hypotheses

Several hypotheses were constructed prior to data collection in order to focus analyses on key issues.

Hypothesis 1: Respondents will favour swaddling for premature infants, reflecting its clinical prominence as a neonatal intervention.

Premature infants are those born before 37 weeks gestation. 60,000 infants are born prematurely in the UK each year (Tommys 2020). As their organs are not fully developed at birth, infants born prematurely are prone to medical problems that necessitate specialized care in a Neonatal Intensive Care Unit (NICU). Swaddling has been used routinely in NICUs for decades "to minimize the sequelae of prematurity" (Zarem, Crapnell et al. 2013)(p111). As detailed in the clinical review (Chapter 5), studies report swaddling of premature infants reduces their expenditure energy, reduces the stress of motor disorganization (Mohammed 2018) and strengthens neuromuscular development (Short, Brooks-Brunn et al. 1996, Neu and Browne 1997, van Sleuwen, Engelberts et al. 2007). I hypothesised that UK health professionals would be familiar with the benefits of swaddling for premature infants and would view the practice favourably relative to swaddling term infants.

Hypothesis 2: Opinions regarding the appropriate age to swaddle will differ by occupation type and occupation duration of the health professionals surveyed.

The healthcare workforce comprises a variety of occupations covering a range of fields. For instance, midwives specialise in the care of mothers and newborns until 2 weeks post-delivery, whereas health visitors have a broader practice range, typically delivering care until infants are around 5 years of age (NHS England 2020). The diversity in clinical training and experience may impact opinions and knowledge of swaddling.

In addition to occupation type, duration of occupation may be an important influence. A 2015 Royal College of Midwives editorial reflected upon the healthcare experience of mothers in 1985, "Once born, her baby would have been taken away to be washed and swaddled before being handed back. Three decades on, many things are different" (Royal College of Midwives 2015)(p39). As detailed in the literature review, historical attitudes toward swaddling have fluctuated, even as recently as the last decade. I hypothesised that the time period in which a professional received their initial training and registration may impact their current views.

Hypothesis 3: Opinions regarding appropriate swaddle locations will differ by occupation duration.

As with hypothesis 2, duration of occupation may affect views pertaining to swaddling location. Recent SIDS recommendations focus on safe sleep environments, with an emphasis in some recommendations for infants to sleep alone in their own bed. In 2012, the 'Back to Sleep' public awareness campaign, which began in 1994, was superseded in the US by a new 'Safe to Sleep' campaign issuing 'rules' emphasizing a continued focus on safe sleep environments and back sleeping (Moon 2016). Rather than issuing rules, the UK revision aimed at 'risk minimization' via parental education (Ball 2017) and was compiled by the National Institute for Health and Care Excellence (National Institute for Health and Care Excellence 2014). This work was later translated into professional guidelines by a group of key public health organisations, resulting in 'Safer Sleep: Saving Babies Lives, a Guide for Professionals' (Public Health England, The Lullaby Trust et al. 2019, The Lullaby Trust 2019). Core messages include discouragement of pillows, cot bumpers and other accessories; the importance of a clear, flat sleep surface; and promotion of room sharing. Interestingly, American studies suggest that the newer recommendations are less familiar to health professionals (Carlin and Moon 2018, Sleutel, True et al. 2018) and several studies have indicated a resistance of some health professionals to adopt them (Colson, Rybin et al. 2009, Colson, Willinger et al. 2013, Shapiro-Mendoza, Colson et al. 2015, Moon, Hauck et al. 2016). Arguably, those professionals more recently registered may be less likely to hold entrenched or outdated views. I therefore hypothesised that professionals with shorter occupational duration will demonstrate views about swaddle location that align with current recommendations.

Hypothesis 4: Opinions regarding the effect of swaddling on various infant outcomes will differ by occupation type.

As with hypothesis 2, specialism in certain infant age-groups across occupation type may influence a respondent's knowledge, experience and views. For instance, in comparison to a midwife, a health visitor may have stronger views on developmental outcomes, reflecting their practice with infants up to 5 years of age (NHS England 2020). In addition to age specialism, topic specialisations differ across occupation types. As a result of their clinical experience, a lactation consultant may have confident opinions on the topic of breastfeeding but weaker views on SIDS. This is because syllabi for qualifying professionals place emphasis on certain areas of practice over others (Howett, Spangler et al. 2006, Eden 2013). In this vein, I hypothesised that occupation type would be associated with knowledge on the outcomes of swaddling.

Methodology

Survey design

This was an exploratory online survey designed to capture the views of specific groups of health professionals. Permission to conduct the survey was granted by the Durham University Anthropology Department Research Ethics Committee. The infrastructure for the survey was provided by JISC Online Surveys, the recommended survey platform for use by staff and students at Durham University.

The survey featured 15 items, selected after a thorough review of the literature (see Appendix 8). Distributed via three digital pages, the items included a mixture of closed-ended and open-ended, multiple choice and Likert-scale questions. The survey began with a clear and concise introduction thanking readers for their participation, outlining the research topic, detailing the aim of the survey, ensuring anonymity and providing an estimate of the time required to complete the survey. The introduction also detailed that participation is entirely voluntary and participants can withdraw at any time. These aforementioned details facilitated informed consent.

The initial five questions sought to ascertain basic demographic information as to occupation, age and gender of the respondents. These questions were followed by detailed questions on the topic of swaddling. The survey did not request identifying information such as name, date of birth, or contact details – participation was therefore anonymous.

To reduce response bias, questions were neutrally worded. Further, to reduce the risk of acquiescence bias (the tendency of respondents to be agreeable), agree/disagree type questions were rephrased as multiple-item questions (Bernard 2011). For instance, rather than asking “Do you agree/disagree that an infant positioner should be used with swaddling?” the survey asked, “Which of the following interventions do you think are appropriate to use with swaddling?” and lists several interventions plus a ‘None of the above’ option.

Adaptive logic was applied where appropriate to automatically exclude irrelevant questions. For instance, question 12 asked “Is swaddle tightness important?” If the option “No” was selected, participants were redirected to question 15 therefore bypassing further questions concerning swaddle tightness.

Where appropriate, questions were complemented by diagrams to ensure reader comprehension. For example, question 9 asked, "Which items of clothing are appropriate to use with swaddling?" accompanied by a diagram showing each item of clothing clearly labelled. This was important as readers may use different colloquial terms. For instance, ‘sleepsuit’ and ‘baby gro’ are often used to describe the same item of clothing. By clearly labelling images of each item, the survey design promoted clarity of reader understanding.

To ensure respondents did not accidentally skip a question, the survey required an answer for every question before the form could be submitted. For potentially sensitive questions (for instance, "What is your gender?") the response option “Prefer not to answer” was included, allowing the respondent to skip the item.

The survey was tested by Durham University staff for usability and technical functionality. Thereafter it was piloted with a convenience sample of health professionals to ensure ease of comprehension and robustness (Kelley, Clark et al. 2003).

Survey distribution

The project used social media and email to distribute ‘open survey’ links to participate on a voluntary basis. Online recruitment methods were chosen as they are associated with lower costs (Harris, Loxton et al. 2015, Lane, Armin et al. 2015, Christensen, Riis et al. 2017) and higher recruitment rates (Wise, Rothman et al. 2015) compared to traditional recruitment methods.

Inclusion criteria required that all respondents were currently professionals in the field of infant care. 'Professional' in this context was understood to mean "Engaged in a specified activity as one's main paid occupation rather than as an amateur" (Oxford English Dictionary 2019). The first survey item requested occupation type, thus screening out respondents that did not meet the inclusion criteria.

Being mindful of the limitations of online surveys in generating representative samples (Ball 2019), and to reduce sampling bias, specific organisations were targeted with requests to share the survey with their members/followers. A link to the survey was circulated via an email campaign for members of the Baby Sleep Information Source (BASIS) mailing list[21]. BASIS was founded in the UK by the Durham Infancy & Sleep Centre and senior representatives from La Leche League, NCT, and UNICEF UK Baby Friendly Initiative with the aim of providing online infant sleep information to parents and/or health professionals (BASIS 2020). Additionally, in effort to get representation from occupational groups, eleven UK-based organisations were contacted: Institute of Health Visiting, Royal College of General Practitioners, British Association of Social Workers, Royal College of Nursing; Bliss, Royal College of Midwives, Doula UK, the Neonatal Infant Feeding Network, the Royal College of Paediatrics and Child Health, the Lullaby Trust and the National Childbirth Trust. Of these, the latter six confirmed having advertised the survey via their social media and email lists. Finally, the survey was advertised on the Durham University Infancy & Sleep Centre’s website and social media accounts. The survey was active for two consecutive calendar months.

[21] 747 people with valid emails.

Results and Analysis

The raw data was downloaded from the survey platform and analysed using SPSS statistical software (IBM Corp 2017). Univariate analysis was used to generate descriptive tabulations for key variables and conduct statistical analyses.

Demographics

196 health professionals completed the survey. This comprised 71 (36.2%) midwives, 45 (22.9%) health visitors, 32 (16.3%) lactation consultants and 48 (24.49%) 'Other'. Of the respondents that selected 'Other', there were 12 (6.1%) nurses, 12 (6.1%) neonatal nurses, 5 (2.6%) doulas, 4 (2%) public health physicians, 3 (1.5%) general practitioners, 3 (1.5%) paediatricians, 2 antenatal educators (1%), 2 (1%) community nursery nurses, 2 (1%) maternity support workers, 1 (0.5%) family centre manager, 1 (0.5%) Montessori infant consultant, and 1 (0.5%) occupational therapist.

In response to a free-text query of how the survey was received, most respondents (n=79, 40.3%) cited an (unspecified) 'email'. The remaining respondents cited the following sources: unspecified Facebook social media (n=32, 16.3%), Baby Sleep Information Source (BASIS) Facebook social media (n=28, 14.2%), Association of Lactation Consultants email (n=20, 10.2%), a colleague (n=15, 7.6%), Institute of Health Visiting email (n=10, 5.1%), BASIS Twitter social media (n=5, 2.5%), Neonatal Infant Feeding Network email (n=5, 2.5%), and BASIS email (n=2, 1%).

The respondents were aged from 25 to 77 years old (mean=48, n=181, missing=15). Most respondents were female (n=194) with 1 male and 1 non-declaration. The length of time the respondents had spent working in the field of infant care ranged from 1 to 45 years (mean=18, n=181, missing=15).

Swaddling and infant age

Likert scales captured the respondents' opinions on the appropriateness of swaddling at various infant age ranges (n=196, missing=0), (Table 21)

Table 21 Infant age and appropriateness of swaddling

	Routine swaddling (every night)	Non-routine swaddling (on occasion)	Not swaddling at all	Don't know
Premature	8.7%	26.0%	46.4%	18.9%
0-1 week	14.8%	43.9%	38.3%	3.1%
1-2 months	12.8%	40.8%	42.3%	4.1%
3-4 months	4.6%	30.1%	60.7%	4.6%
4-6 months	3.1%	13.8%	79.1%	4.1%

6-8 months	0%	8.2%	87.2%	4.6%
8-10 months	0%	6.6%	88.3%	5.1%
10-12 months	0%	6.1%	89.3%	4.6%

These results did not support the hypothesis: 'Respondents will generally favour swaddling for premature infants', with most respondents (n=91, 46.4%) believing premature infants should not be swaddled at all. When responses were filtered by occupation, midwives were slightly more likely to hold this view 58% (41/71) than health visitors 51% (23/45). To assess whether there was a relationship between infant maturity at birth and HP approval of swaddling a Pearson Chi Square was performed on dichotomised infant age variables 'Preterm' and 'Term' and HP response 'Swaddling OK' and 'Swaddling not OK'. Significantly more HPs indicated that Swaddling was OK for term infants, and not OK for preterm infants than expected by chance ($\chi 2 = 10.946$, df = 2, $p < .05$).

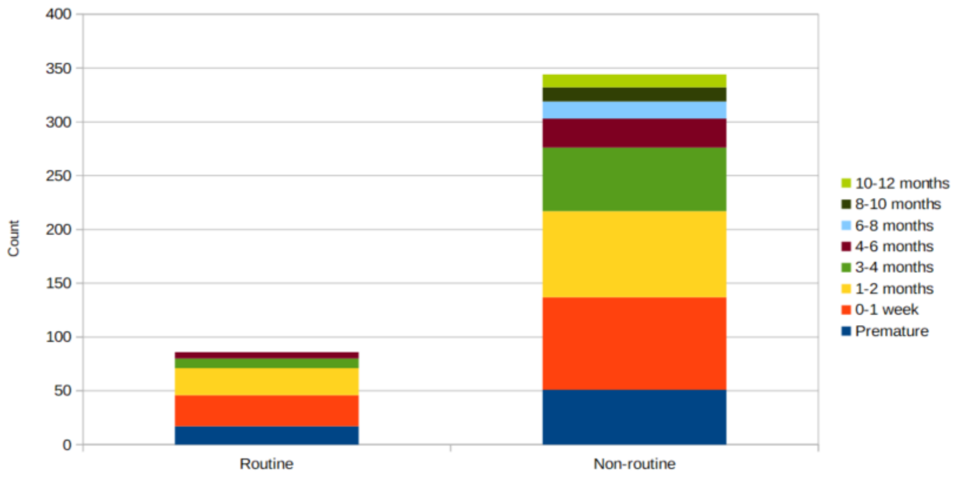
In exploring the hypothesis: 'Opinions regarding the appropriate age to swaddle will differ by occupation type and occupation duration', I compared the duration of occupation for people who thought swaddling was OK past 4 months (guideline for swaddle cessation at the time of data collection)[22] with those who thought it was not okay past 4 months. To enable this, I created the new variable 'After 4 months'. For this I used the data from 4-6 months and combined 'Routine swaddling every night' and 'Non-routine swaddling' into 'Swaddle OK' to contrast with the value 'Swaddle not OK'.

A Shapiro Wilk test indicated that the sample distribution of the occupation duration data was significantly different from the normal distribution ($p <.001$). Therefore, a non-parametric test, Mann-Whitney test, was performed on this variable. The results indicate a significant association between occupation length and opinion on swaddling after 4 months (U = 3109.000, p = .026). HPs who reported that swaddling over 4 months of age was OK had a median occupation duration of 13 years, compared to those who reported it was not OK, median = 20 years.

In terms of routine versus non-routine swaddling, most respondents favoured non-routine swaddling across all infant age ranges (Figure 48).

[22] McDonnell, E. and R. Y. Moon (2014). "Infant deaths and injuries associated with wearable blankets, swaddle wraps, and swaddling." J Pediatr **164**(5): 1152-1156, Moller, E. L., W. de Vente and R. Rodenburg (2019). "Infant crying and the calming response: Parental versus mechanical soothing using swaddling, sound, and movement." PLoS One **14**Calkins, S. D. and A. C. i. o. e. e. r. I. H. o. e. r. Hill (2007). Caregiver influences on emerging emotion regulation. Handbook of emotion regulation. London, Guilford Press.: e0214548.

Figure 47 Routine versus non-routine swaddling by infant age, stacked bar chart



Swaddle location

Likert scales detailed the respondents' opinions on the appropriate infant location for swaddling (n=196, missing=0) (Table 22).

Table 22 Swaddle location

	Yes	No	Only when parents can see infant	Don't know
Cot in parents' room	28.1%	32.1%	39.3%	.5%
Cot in separate room	6.1%	85.2%	7.7%	1.0%
Car seat	.5%	98.0%	.5%	1.0%
Baby sleep box	14.8%	53.1%	26.0%	6.1%
Pram	9.2%	62.2%	27.6%	1.0%
Sling worn by parent	4.6%	87.8%	4.6%	3.1%
Bedside bassinet	26.6%	37.8%	33.2%	.5%
Adult bed with parents	2.0%	92.3%	4.6%	1.0%

For each location variable, I combined the responses 'Yes' and 'Only if parents can see them' into the new value ‘Swaddle OK’ to contrast with ‘Swaddle not OK’. Next, I used the ‘occupation duration’ variable to address the hypothesis: ‘Opinions regarding appropriate swaddle locations will differ by occupation duration’. As the sample distribution of the occupation duration data was significantly different from the normal distribution, a non-parametric test, Mann-Whitney, was performed on this variable. The results indicate an association between occupation duration and stance regarding two locations: Baby sleep box and Bedside bassinet (Table 23). HPs who reported that swaddling in a baby sleep box was OK had a median occupation duration of 14.5 years, compared to those who reported it was not OK, median = 20 years. HPs who reported that swaddling in a bedside bassinet was OK had a median occupation duration of 15 years, compared to those who reported it was not OK, median = 20 years.

Table 23 Mann-Whitney test results, Occupation v Swaddle location

Location	**Test outcome**
Cot in parents’ room.	(U = 4571.500, p = .088).
Cot in separate room.	(U = 2233.500, p = .504).
Car seat.	(U = 154.000, p = .671).
Baby sleep box.	(U = 4858.500, p = .011).
Pram.	(U = 4067.000, p = .601).
Sling worn by parent.	(U = 1311.000, p = .528).
Bedside bassinet.	(U = 5196.000, p = .016).
Adult bed with parents.	(U = 1445.500, p = .133).

Swaddle outcomes

In response to the question, ‘Do you think the following behaviours are affected by swaddling?’ Likert scales detail the respondents’ opinions (n=196, missing=0) (Table 24).

Table 24 Swaddle outcomes

	Increases	Decreases	No effect	Don’t know
Arousals (waking up)	1.5%	64.8%	15.8%	17.9%
Startles	.5%	81.1%	9.7%	8.7%
Movement	1.0%	82.1%	11.7%	5.1%
Heart rate	12.8%	26.0%	15.3%	45.9%
Respiration	13.3%	22.4%	19.9%	44.4%
Temperature	72.4%	3.1%	11.7%	12.8%

Breastfeeding	3.1%	43.9%	30.1%	23.0%
Bottlefeeding	2.0%	27.6%	37.2%	33.2%
SIDS risk	66.8%	4.1%	14.3%	14.8%
Motor development	1.5%	48.0%	23.5%	27.0%
Cognitive development	3.6%	29.1%	28.6%	38.8%
Language development	2.0%	18.9%	33.2%	45.9%
Emotional development	10.2%	30.1%	21.9%	37.8%
Sleep duration (deep sleep)	50.0%	1.5%	14.3%	34.2%
Sleep duration (active sleep)	25.5%	10.7%	14.3%	49.5%
Crying	8.2%	54.6%	10.2%	27.0%
Sleep cycles (transitions from deep to active sleep)	16.8%	14.8%	17.9%	50.5%

Pearson Chi-square tests compared all swaddle outcomes with the four occupational groups: Midwives (n=71), Health Visitors (n=45), Lactation Consultants (n=32), and Other (n=48). Results indicated statistically significant associations between occupation type and opinion on several infant outcomes (Table 25).

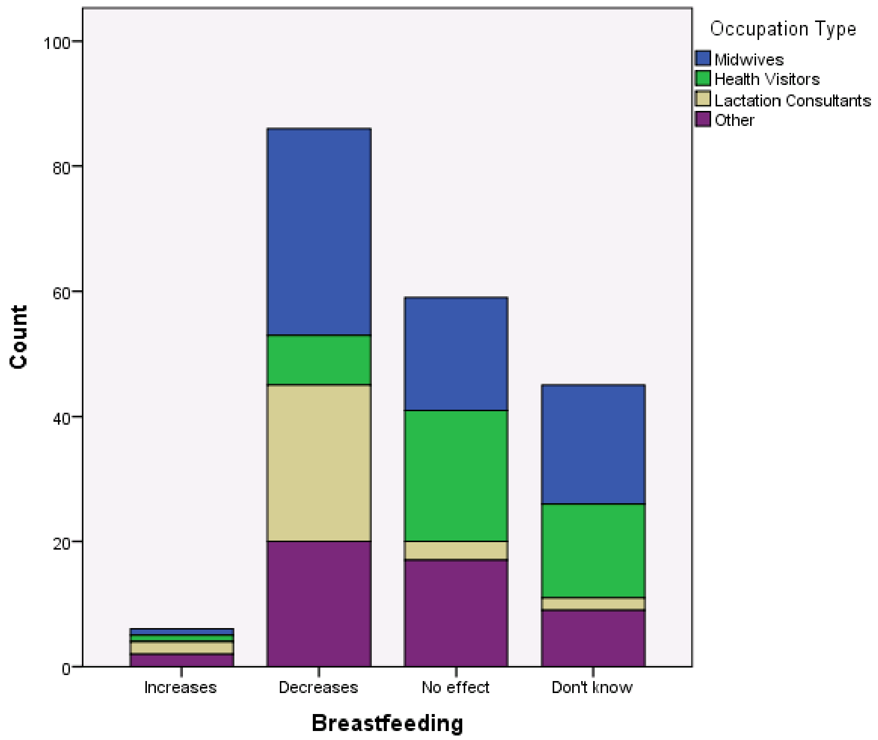
Table 25 Swaddle outcomes, Pearson Chi-square results

	X2	df	p
Arousals (waking up)	22.12	2	.008
Startles	7.77	9	.557
Movement	17.24	9	.045
Heart rate	12.50	9	.186
Respiration	19.50	9	.021
Temperature	12.76	9	.174
Breastfeeding	34.16	9	.000
Bottlefeeding	10.25	9	.330
SIDS risk	16.99	9	.049
Motor development	24.55	9	.004
Cognitive development	19.11	9	.024
Language development	7.34	9	.601
Emotional development	19.66	9	.020
Sleep duration (deep sleep)	17.91	9	.036
Sleep duration (active sleep)	20.94	9	.013
Crying	23.26	9	.006

Sleep cycles (transitions from deep to active sleep)	25.65	9	.002

The most significant association was found between occupation type and opinion on effects of swaddling on breastfeeding (p=.00). The belief that swaddling decreases breastfeeding was dominant for 46.5% Midwives (n=33/71), 78.1% Lactation Consultants (n=25/32), and 41.7% Other (n=20/48). The belief that swaddling has no effect on breastfeeding was the dominant response for Health Visitors only: 46.7% (n=21/45). Thus, there was a significant positive association between Health Visitors and the opinion that swaddling has no effect on breastfeeding. When answering 'No effect on breastfeeding', the actual count for Health Visitors (21) was significantly higher than the expected count if the null hypothesis were true (13.5) (Figure 49).

Figure 48 'Do you think breastfeeding is affected by swaddling?', stacked bar chart



Swaddle technique

<u>Style</u>

In response to the multiple-choice question, "Which of the following images most resembles the swaddle technique/s you might show or recommend to parents?" there was no dominant swaddle technique preferred by the majority of respondents (Figure 50). Arm positioning was a key feature. Traditional swaddle techniques such as the Diamond held favour over modern variants such as the zip up swaddle pod (Figure 50).

Figure 49 Swaddle technique, pie chart

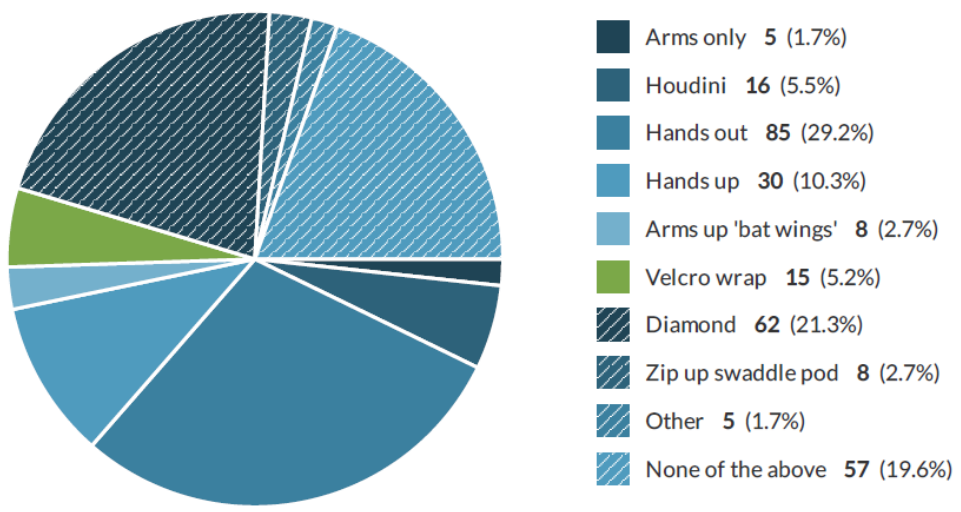
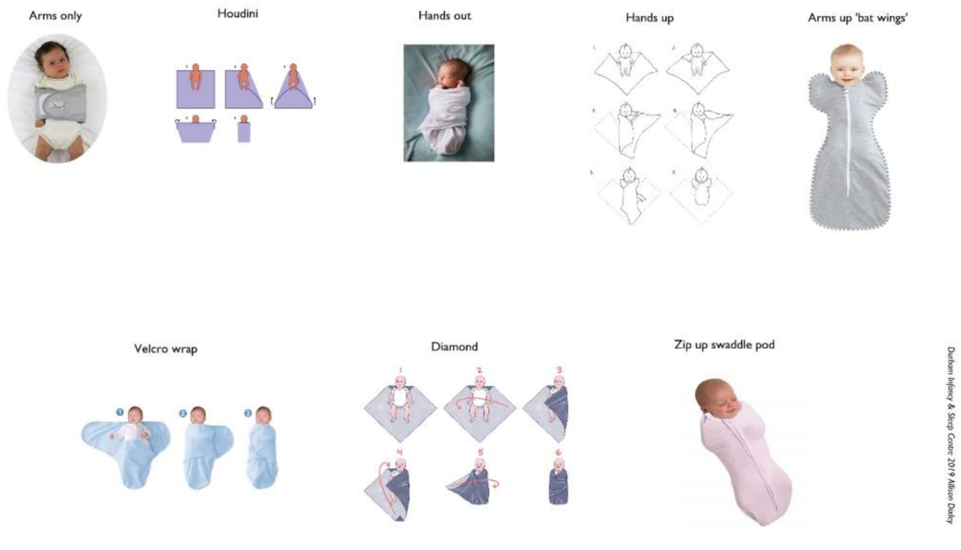


Figure 50 Swaddle technique images as presented on survey



<u>Clothing</u>

In response to the multiple-choice question, 'Which items of clothing are appropriate to use with swaddling? (Items may or may not be used simultaneously)' the most popular items were those worn on the trunk of the body. The last popular items were those worn on the extremities, with the exception of the bib (Figure 52).

Figure 51 Clothing, pie chart

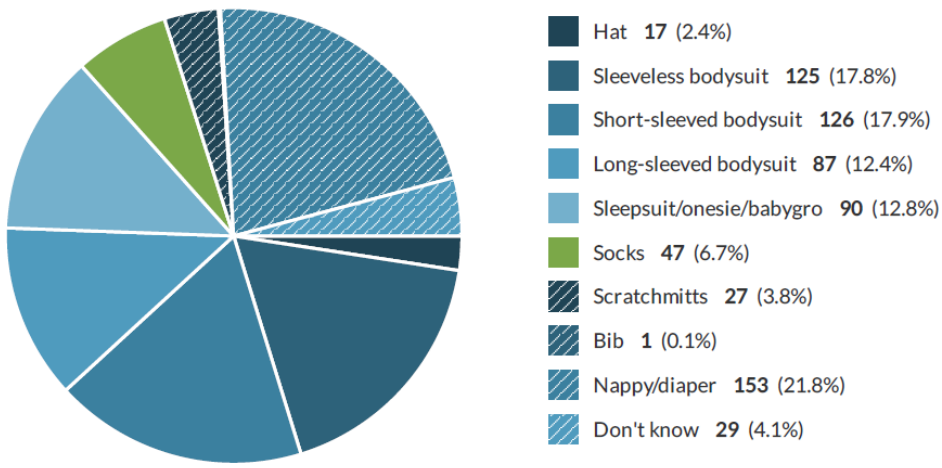


Figure 52 Clothing images, as presented on survey

<u>Layers</u>

In response to the free-text question, 'How many layers (including the swaddle) do you believe should be used when swaddling?', 155 (79%) respondents offered an opinion. Of those, 'two layers' was the most commonly cited response (n=49, 31.6%), followed by 'one layer' (n=40, 25.8%), 'depends on the environment temperature' (n=29, 18.7%), 'three layers' (n=23, 14.8%), 'two or three layers' (n=10), and 'one more layer than parent is wearing' (n=3, 1.9%). Only one respondent replied, 'depends on swaddle material'.

Co-occurring interventions

In response to the multiple-choice question, 'which of the following interventions do you think are appropriate to use with swaddling? (select all that apply)', sensory stimuli such as dummies and white noise were relatively popular. Within-cot devices varied in popularity with the breathing sensor mat significantly more acceptable than the positioner and sleep pod. Outside-cot containers such as the motorised swing and vibrating bouncer were relatively unpopular (Figure 54 & 55).

Figure 53 Co-occurring interventions, pie chart

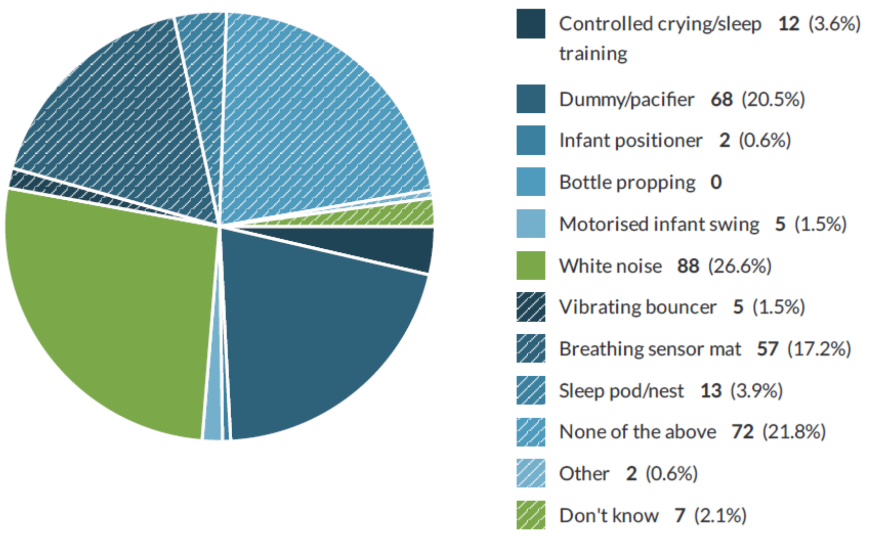


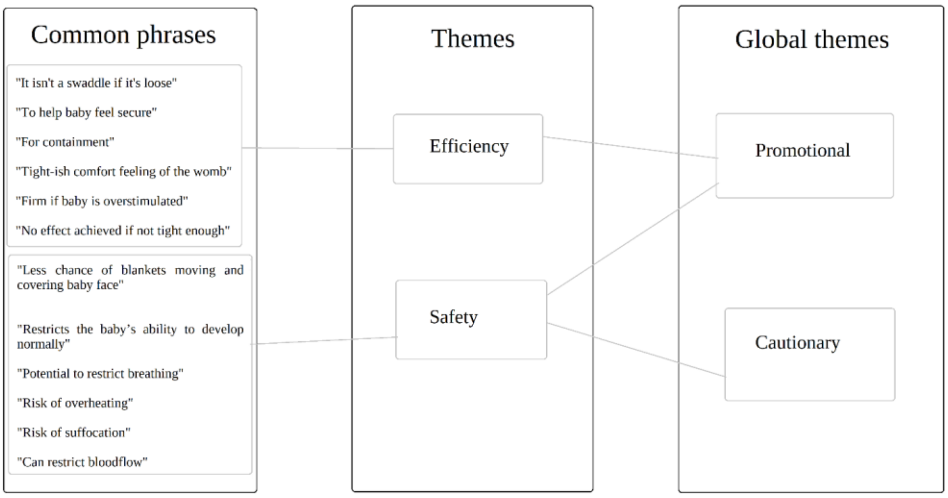
Figure 54 Co-occurring interventions images, as presented on survey

<u>Tightness</u>

Regarding the tightness of the swaddle, most respondents (n=138, 70.4%) thought tightness was important, whilst 21 (10.7%) thought tightness was not important, and 37 (18.9%) were unsure whether tightness was important.

Those respondents that indicated tightness was important were filtered to the free-text question, 'In your view, why is swaddle tightness important?' A thematic analysis of the free-text responses revealed two central themes: Efficiency (effectiveness of the swaddle to achieve the desired outcome) and Safety (safeguarding infant health). Regarding the latter, tightness was viewed as either promotional or cautionary (Figure 56).

Figure 55 Tightness, thematic analysis diagram



The following quotes are indicative:

> *"Too tight restricts the baby's ability to grow and develop normally, too loose could be a safety issue".*
>
> *"If the swaddle is too loose it does not reassure the baby and if it is too tight, baby cannot protect airway".*
>
> *"If swaddling isn't restrictive it isn't helpful in settling and keeping baby asleep".*

Discussion

Swaddle duration

Newborns were thought most appropriate for swaddling. These findings echo the Australian survey[23] and reflect current advice; e.g., the Baby Sleep Info Source (BASIS) information sheet for health professionals states: "Swaddling is safest from birth, don't suddenly start when SIDS risk is highest (2-3 months old)" (BASIS 2018).

[23] In the Australian survey, most respondents (89%) believed that swaddling was most appropriate for infants aged between birth and three months.

Of note are attitudes towards the swaddling of premature infants; most respondents believed premature infants should not be swaddled at all. This finding echoes the Australian survey.[24] If either survey had involved a greater number of professionals with NICU training and/or experience, a more positive attitude towards swaddling may have emerged. In the U.S. 86% of infants are swaddled in Neonatal Intensive Care Units (Field, Hernandez-Reif et al. 2006). Unsurprisingly, the 2013 American study of neonatal nurses and therapists indicated the predominantly pro-swaddling stance of those professionals (Zarem, Crapnell et al. 2013).

Interestingly, HPs who approved of swaddling over 4 months of age had on average seven years less occupational experience than those disapproving (13yrs versus 20yrs). It is possible than more recently trained HPs have less practical observation of swaddled older infants, given the contemporary decline in swaddling this age group (McDonnell and Moon 2014, Moller, de Vente et al. 2019, American Academy of Pediatrics 2020).

In terms of routine versus non-routine swaddling, most respondents across all infant age ranges preferred non-routine swaddling. This opinion reflects views of the 1960s and 1970s where authors recommended swaddling be used 'during episodes of irritability' (Lipton, Steinschneider et al. 1965, Wolff 1966, Brackbill 1971, Giacoman 1971). It reflects the contemporary view of the Royal College of Midwives which state that swaddling could be useful as "a temporary short-term intervention" (Royal College of Midwives 2012)(p40). It also reflects the view of modern scholars who argue that health professionals should encourage physical contact between infants and caregivers "as much as possible" and aim to "reduce separative practices" (Berecz, Cyrille et al. 2020)(p2). The topic of non-routine swaddling is potentially important however, as evidence suggests that parents in Western cultures choose to swaddle routinely rather than non-routinely. In one American study, 72.8% of parents that swaddled reported engaging in the practice at least once daily, and 44% reported swaddling more than twice a day (Oden, Powell et al. 2012). Crucially, as detailed in the biobehavioural review (Chapter 4), studies have suggested significant differences in outcomes for infants inexperienced with swaddling compared to those routinely swaddled. Guidelines recommend that swaddling "should be done for each day and night time sleep as part of a regular routine" (The Lullaby Trust 2020).

In light of limited official guidelines as to the safety of swaddling[25], it is possible that the findings of the present survey reflect an over-cautious approach similar to the "ethical discomfort" previously felt about bedsharing (McKenna and Gettler 2017)(p4). In this vein, the 2016 NHS England commissioned 'National Maternity Review' (NHS England 2016) explored, amongst other things, the views of health professionals working in maternity services in England. The review cited:

> *"Professionals told us that the threat of litigation and the high costs associated with it could encourage colleagues to practise in a risk-averse way, inhibiting their ability to support some of the choices that women may want to make" (p39).*

[24] Only 9% of respondents in the Australian study were aware of the potential benefits of swaddling premature infants.
[25] See Chapter 5 Clinical Review.

Swaddle technique

To date, there remains no standard protocol developed anywhere in the world for healthcare professionals to recommend an optimal swaddling technique to parents (Fletcher, Pham et al. 2018). This deficit was reflected in the eclectic range of preferences selected by respondents in this study. Mirroring the Australian survey, 'hands out' was the most popular technique, a finding that corroborates recommendations to leave arms free for babies over 3 months for self-soothing (BASIS 2018). The traditional 'Diamond' technique was the second most popular option, a style commonly recommended in the literature of commercial swaddle manufacturers (Aden and Anais 2020, Bellamy's Organic 2020, Karp 2020, Kyte Baby 2020, Swaddle Designs 2020). These findings also reflect the variation in newborn nursery and NICU swaddling techniques recorded in a recent American observational study of professionals (Fletcher, Pham et al. 2018).

On the issue of clothing, only 2.4% of respondents in the present study believed it appropriate to apply a hat whilst swaddling, mirroring UK guidelines (BASIS 2018, National Childbirth Trust 2020). As detailed in the sociohistorical review (Chapter 3), risk of overheating is especially crucial among some ethnic or cultural groups where it is believed infants need to be kept very warm. In some communities, it is common practice to cover the infant's head during sleep periods. Yet as the head is the site of 40% of heat production and around 85% of heat loss, it is important that heat can dissipate through this surface (Blair, Mitchell et al. 2008).

Despite findings indicating an appreciation of the risks of overheating, only one respondent cited type of swaddle material when considering the appropriate number of layers. UK recommendations urge infants to sleep "with bedding and clothing that is suitable for the room temperature"(The Lullaby Trust 2020), and to swaddle using thin (The Lullaby Trust 2020), breathable (National Childbirth Trust 2020) material.

UK recommendations were however reflected in the respondents' views of appropriate sleep locations (BASIS 2018, National Childbirth Trust 2020, The Lullaby Trust 2020), with an overall negative view of the use of co-occurring interventions (McDonnell and Moon 2014, The Lullaby Trust 2020) and a belief in the importance of swaddle tightness (The Lullaby Trust 2020). Regarding the latter, concerns that the infant would have trouble breathing if swaddled too tightly mirror the views of parents expressed in other studies (Oden, Powell et al. 2012). Indeed, the degree of swaddle tightness impacts the degree to which the infant's lungs can expand and lung restriction has been linked to an increase in lower respiratory tract infections. In one study, tight swaddling increased the risk of developing respiratory infections fourfold (Yurdakok, Yavuz et al. 1990).

Interestingly, hip dysplasia was not a commonly cited concern. Only 10.87% of those respondents answering the question 'Why is swaddle tightness important?' mentioned the topic of hips. Further, the most hip-friendly swaddle style 'arms only' was the least popular of the 10 'swaddle technique' options (n=5, 1.7%). These findings echo the American survey in which risk of hip dysplasia was the topic least discussed with parents. A similar deficit was also highlighted in the Australian survey, with only 6% of those respondents identifying hip dysplasia as a risk of swaddling. Further still, the results corroborate those of the Indian survey in which only 6.6% Paediatricians and 0% nurses were aware of 'hip-safe swaddling'. The Arabian survey, which focused entirely on DDH found that almost one-third of the respondents had practiced swaddling, with only 42% of them using the safe technique. As detailed in the clinical review (Chapter 5), studies have clearly and consistently shown correlation between swaddling and risk of developmental dysplasia of the hip. Contemporary resurgence of swaddling has occurred simultaneously with a decrease in the use of bulky cloth nappies that better maintained infant hips in abduction and flexion (Charlton, Schoo et al. 2017). One 2016 study using sonography to examine a group of infants being treated for DDH, objectively demonstrated that tight swaddling limited hip flexion and even dislocated one unstable hip (Harcke, Karatas et al. 2016).

Swaddle location

An association between occupation duration and health professional stance was indicated regarding two locations: baby sleep box and bedside bassinet. HPs that approved of swaddling in a baby sleep box had around 5 years *less* occupational experience than those disapproving of the location (14.5yrs versus 20yrs). Similarly, HPs that approved of swaddling in a bedside bassinet also had 5 years less occupational experience than those disapproving of the location (15yrs versus 20yrs). These outcomes may have resulted from updated training practices. In 2014, bedside bassinets were introduced in some NHS hospitals (Robinson 2014). Likewise, in 2016, programmes offering baby sleep boxes to parents began in some NHS Trusts (Ball and Taylor 2020). HPs trained more recently may thus be more accepting of those devices than HPs with relatively dated training.

Swaddle outcomes

Corroborating the AAP stance on clothing and layers (Goodstein, Hauck et al. 2016), most respondents of the survey (72.4%, n=142) cited that swaddling increases infant temperature. This finding reflects UK recommendations advising that swaddled infants should be routinely checked for over-heating (National Childbirth Trust 2020, The Lullaby Trust 2020). The response is similar to the Indian survey, in which 82.90% of nurses cited swaddling for warmth.

On the topic of arousal, most respondents (81.1%) identified decreased startles as a likely outcome of swaddling, in line with the Australian survey (73%). Further, 50% of respondents believed swaddling increased duration of sleep, precisely mirroring the Australian data (50%). As detailed in the biobehavioural review (Chapter 4), empirical research has shown swaddling to influence both outcomes, although data remain inconsistent.

In contrast to the Australian survey, 66.8% of respondents believed that swaddling increased risk of SIDS, compared to only 26% of Australian respondents. This discord reflects the inconsistency of evidence associating swaddling with SIDS, discussed in the clinical review (Chapter 5). In further discord, most UK respondents (54.6%) thought that swaddling reduced crying, compared with only 33% of Australian respondents. Yet a body of research suggests that responding to crying with parental touch is preferable, as this stimulates the development of the infant's emotional brain, leading to greater emotional stability in later life (Gerhardt 2015).

Indeed, the early weeks of an infant's life are universally thought to have a major influence on their later physical, social, emotional and language development (Wave Trust 2013, Institute of Health Equity 2020). Yet when asked whether swaddling affected emotional development, most respondents indicated uncertainty (n=74, 37.8%), followed by the opinion that swaddling decreased emotional development (n=59, 30.1%). Similar findings were seen regarding cognitive and language development. This is perhaps to be expected, as the long-term effects of swaddling are largely unclear owning to lack of longitudinal data. One randomized controlled trial of 1279 infants that were tightly swaddled for the first 7 months of life failed to find harmful effects on psychomotor and mental development scores at 13 months of age (Manaseki-Holland 2010).

The most significant finding in this survey was the association between occupation type and opinion on the effects of swaddling on breastfeeding. The belief that swaddling decreases breastfeeding was the dominant response for Midwives, Lactation Consultants, and Other. Most health visitors on the other hand, indicated that swaddling has no effect on breastfeeding. The impact of swaddling upon feeding remains unclear to date. The UK has one of the poorest breastfeeding continuation rates in the world (Victora, 2016, as cited in Ball and Blair 2017). Most studies exploring swaddling have failed to distinguish between breast- and bottle-fed infants (Dixley 2015). The few that specifically investigated breastfeeding have produced conflicting results. A 2007 Russian randomized trial of newborn infants (Bystrova, Widstrom et al. 2007) failed to ascertain a difference in breastfeed duration and frequency between swaddled and unswaddled infants. A systematic review undertaken in the same year also found no correlation between swaddling and breastfeeding behaviour. However, every randomized control trial featured in the review compared swaddling with practices involving separation from mother, such as the use of incubators or pacifiers (van Sleuwen, Engelberts et al. 2007). Other data suggest that swaddling immediately after birth may interfere with breastfeeding and with mother-infant interaction generally (Safari, Saeed et al. 2018). Early swaddling has been repeatedly associated with a decrease in the demonstration of infant feeding cues (Jansson, Mustafa et al. 1995, Moore and Anderson 2007) and with decreased infant "wakefulness" during breastfeeding 4 days after birth (Dumas, Lepage et al. 2013). Further research investigating the impact of swaddling upon breastfeeding is needed.

The statistically significant association between occupation type and opinion on a range of infant outcomes may be a product of concerns outlined in the National Maternity Review (NHS England 2016). The review recognised "a culture of silo working and a lack of respect across disciplines" (p38). Indeed, the review highlighted that "Many women expressed frustration over receiving conflicting advice from different healthcare professionals throughout their care" (p33). Of note was the relationship between midwives and health visitors:

"After the birth of the baby, the midwife will hand over to the health visitor. The importance of maternity services working with and ensuring a proper handover to health visitors has already been outlined. Good outcomes are seen when midwives and health visitors work together on issues like breast feeding" (p59).

The review recommended multi-professional training, recognising that, "those who work together should train together" (p10). In line with this recommendation, and corroborating the Australian and American surveys, the present study identified the need for detailed evidence-based guidelines to promote consistency in practice across infant care occupational roles. Such guidelines should consider differentiation between swaddle techniques and family motivations. In exploring health professionals' knowledge and opinions on the breadth of potential swaddling practices, this study provides a benchmark for the development and delivery of thorough practice-based guidelines.

Clinical implications

- The findings indicate a high level of professional knowledge pertaining to UK safe sleep infant-care recommendations. Knowledge is particularly strong concerning sleep location, prevention of over-heating, and the risk associated with additional interventions such as sleep pods and positioners.
- Whilst knowledge is generally up to date in line with UK recommendations, this survey builds upon previous concern that health professionals are no longer counselling families on the risk of hip dysplasia associated with tight swaddling.
- The survey highlights an underappreciation for the potential utility of swaddling premature infants. This may cause confusion for families as they transition from NICU to community care.
- Respondents significantly preferred non-routine swaddling over routine swaddling. It is possible that families are being counselled to engage in sporadic swaddling, against their own judgements, despite dubious epidemiological evidence supporting this practice, and some indication that inconsistency in infant sleep practices is associated with increased SIDS risk.
- Opinions regarding the impact of swaddling upon breastfeeding are polarised, and families are likely to receive conflicting advice on this topic. Inconsistency of advice can lead parents to view evidence as "not reliable" and guidelines as "optional" (Lau and Hall 2016)(p2822).
- In absence of official guidelines as to the safety of swaddling, the findings indicate an over-cautious approach and general aversion to swaddling among UK health professionals. This may potentially alienate those families who wish to swaddle for personal or cultural reasons.

Strengths

This study is the first known UK survey of health professionals investigating swaddling and the most comprehensive survey on the topic. Distribution was more widespread than previous foreign attempts. For instance, respondents to the Indian and Arabian surveys were based at a single institution. In contrast, the present survey captured a wide range of occupation types and respondents across the age spectrum at varying lengths of employment at various institutions.

Each foreign survey was paper based in contrast to the present survey which was conducted online. E-mail methods have been shown to be more effective at recruiting older participants, whilst social media more effective at recruiting young adults (Nolte, Shauver et al. 2015, Buckingham, Becher et al. 2017). As expected, the use of both sources produced a higher recruitment rate and more diverse demographic spread than previous swaddling surveys of health professionals conducted using traditional methods[26]. Data obtained via online methods are thought to have similar validity as data obtained via traditional methods (Christensen, Ekholm et al. 2014, Krogh, Larsson et al. 2016). Scholars have deemed social media to provide a reasonable "high-quality alternative" to a representative sample, given the diversity of the potential population of respondents (Kosinski, Matz et al. 2015)(p545).

Limitations

It was not possible to generate a comprehensive sample or a random representative sample using the chosen methodology. Further, as it was impossible to track the number of people that viewed the websites, social medias, and forwarded emails, a robust response rate could not be determined. As an exploratory study, the aim of the survey was to qualitatively capture a wide range of views about swaddling rather than assess the national prevalence of any view.

Lack of variation in gender and location, and absence of ethnicity data reduce generalisability, although the vast majority of midwives, health visitors and lactation professionals in Western cultures are women (Wright 2000, Smith 2003, Jones 2013, Bly, Ellis et al. 2020). Additionally, despite distribution via predominantly UK sources, there was no mechanism to prevent international participation.

Concerning survey bias, the controversial nature of swaddling posed greater risk than less controversial topics (Ball 2019). It is possible those professionals who chose not to respond or who abandoned the survey prematurely were characteristically different from those that chose to complete it. The findings may over-represent those with a strong opinion on swaddling or those with the most swaddling experience. It is also possible that participants responded with perceived ideal answers, thereby giving what they considered to be the best or more appropriate answer to each item, an approach which may not reflect their actual practice patterns. 15 respondents claimed to have discovered the survey via a colleague; Assuming colleagues share similar interests or perspectives, this may have led to over-representation of a particular viewpoint. Further exacerbating this problem, the interface of Jisc Online surveys, does not prevent a survey from being completed more than once on the same computer or from the same IP address.

[26] Present study and Australian study comparison: 196 participants versus 161; participant age range of 25 to 77 versus 35–54; several occupation types versus one occupation type.

Finally, the second largest group of respondents, health visitors, are qualified and registered nurses or midwives who have chosen to gain additional training and qualifications as specialist community public health nurses (NHS England 2020). A health visitor that has previously practised as a midwife may have significantly different clinical experience and views to one that practised as a nurse. Therefore, more detailed occupational information would have enhanced analysis.

Conclusion

The opinions and beliefs explored in this survey reflect a typically Western clinical view of swaddling, a view that shows evidence of shifting and morphing alongside a changing cultural and professional zeitgeist. This study is an important gateway into the exploration of professional discourses on swaddling. Providing comprehensive data on swaddling practices, this study establishes a benchmark against which practitioner training and the development of practice-based guidelines can be assessed.

Chapter 10. Overall discussion

Introduction

> *"Even if an infant has largely coped with an independence-promoting strategy, as a culture we have to ask ourselves, what have they learned?"* (Miller and Commons 2014)(p128).

Bringing together the biological and cultural arms of anthropological enquiry, in this chapter I summarise and integrate the collective findings from all four projects. To unpick the many interwoven dynamics embedded in my findings, I begin this chapter by adopting a thematic approach organised in 4 sections. Section 1 frames my research in the context of the mother-baby dyad as an integrated unit. Here, I use the distal/proximal dichotomy to generate new theoretical critiques. This discussion flows into Section 2 which critically explores the concept of the womb as a holding unit for the infant and the belief that this phenomenon can be replicated by swaddling. I argue that mimicking the womb environment is unhelpful and possibly even harmful. I further critique the swaddling-as-maternal assumption in Section 3 where I argue that, rather than mimic maternal function, swaddling deprives the infant of such comfort which in turn triggers a stress response. Here I elaborate on the theoretical roots I placed down in the biobehavioural review and attempt to explain the complex nature of habituation through systems theory. After summarising the consequences of this process for the infant, I turn back to the dyad in Section 4. I explore maternal use of swaddling as a tool to negotiate the competing demands of the infant and her own needs. I explore in further detail how perception of needs, familial influences, and resource availability intersect to nudge mothers towards making particular trade-offs.

After this thematic discourse I present a high-level overview of my contribution to knowledge via this thesis, looking at the broad spectrum of 'spheres of enquiry', from the physiological to the contextual. Finally, I present limitations and reflections, highlighting common themes and challenges, and synthesizing recommendations for further research.

Section 1. The effect of swaddling on the mother–infant relationship

> *"By around the fourth month, the infant begins to recognise the mother as source of boundless freedom when it is unswaddled for however long an interval and then of unbounded slavery as it is rewrapped" (Dervin 2008)(p225).*

In 2004 McKenna observed that "it is the dyad, and not the infant, that constitutes the major unit for study and analysis" when considering infant care practices (McKenna 2004)(p513). Over a decade later, his observation has been reinforced with a 2018 systematic review giving credence to the dyad as a mutually regulated, dynamic 'interactional system' (Provenzi, Scotto di Minico et al. 2018). The inter-embodied nature of the mother-infant relationship was detailed in Chapter 5 (clinical review) where swaddling was proposed as a 'dyadic intervention' for numerous ailments including postnatal depression (Giallo, Gartland et al. 2015).

Within this context, the term 'dyadic synchrony' refers to the character of mother-infant interactions and has been broadly conceptualized as "an observable pattern of dyadic interaction that is mutually regulated, reciprocal, and harmonious" (Harrist and Waugh 2002)(p555). Provenzi et al.'s systematic review found that dyadic synchrony is consistently linked to more positive infant outcomes (Provenzi, Scotto di Minico et al. 2018). Synchrony is considered to be a key aspect of early parenting, defined as "infant and adult taking turns in the communication, both being involved in initiating, sustaining and terminating the action" (Unicef UK Baby Friendly Initiative 2001)(p96).

1.1 The proximity dichotomy

Infant-mother physical proximity is "much more than just a nice social idea", it's a biological imperative (McKenna 2016)(p208). This thesis builds upon the work of previous anthropologists, not only by highlighting the interrelationship of bodily proximity and breastfeeding (Ball, Tomori et al. 2019), but by broaching new questions on this topic. Can mother-infant proximity accurately be measured in terms of physical distance alone (room sharing, bedsharing), or should our investigations include physical barriers such as the wrap of a swaddle or the walls of a bassinet? Certainly, swaddled infants can be close to their mothers in terms of physical proximity but arguably remote in terms of *biobehavioural proximity*. As highlighted in Chapter 3 (sociohistorical review), measures of mother-infant interaction can be grouped into two dichotomous categories: proximal and distal. Interactions characterized by bodily proximity and body stimulation (touch, movement etc) are regarded as 'proximal', whilst interactions characterized by communication through the distant senses are known as 'distal' (Keller and Otto 2009, Keller, Hentschel et al. 2016). Proximal infant care orchestrates a very different "dyadic dance" to distal infant care, and vice versa (Provenzi, Scotto di Minico et al. 2018)(p16).

It is my contention that swaddling forces the dyad to adopt predominantly distal interactions. This suggestion is novel, given that the proximal/distal dichotomy has not previously been applied in the swaddling context. However, there is considerable empirical support for the proposition. Swaddling, as a practice, emphasizes autonomy and separateness and limits physical contact between infant and mother, and just like distal care, is typified by communication via sight and sound. In observing this, social anthropologist Ioannis Tsoukala noted that, "By being immobilized, infants wear their hearts on their faces" (Tsoukala 2018)(p48).

Also as detailed in Chapter 3 (sociohistorical review), in many cultures – including our own, swaddling is seen as an effective replacement for the 'containing' functions of the mother (Stork 1986, Mellier 2010). This assumption renders maternal proximity as dispensable (Franzblau 1999). Certainly, studies have linked swaddling with a reduction in instances of maternal touch (Ferber, Kuint et al. 2002, van Gestel, L'Hoir et al. 2002).

I interpret the evolutionary literature on this topic to imply that primate infants are primed to expect proximal care (Ball 2008), whereas human mothers may deliver a mixture of proximal and distal care depending on their social circumstances and access to resources (McKenna 2016). In fact, when observing apparent maternal indifference to infant death in some cultures (Scheper-Hughes 1985), scholars have advanced the idea that evolution favoured the formation of an initially weak mother-infant attachment (Johow, Voland et al. 2014, Keller, Otto et al. 2014, Lancy 2014, Weisner, Otto et al. 2014) that facilitates modulation of maternal investment (Panter-Brick & Ball 2001). There are numerous fitness benefits of initially weak attachment of the mother to her baby and reduced proximal investment. Among these, include a mother's motivation to conceive again as soon as possible (Lancy 2014). I argue the distal function of swaddling in separating and concealing the infant body from the maternal senses, dehumanizes the infant, suppressing the infant's ability to solicit touch and/or interaction, and in doing so, weakens the infant's affective ties with their parents, which (from an evolutionary theory perspective) may already be precarious.

A limitation of my explanation lies in its ethnocentric nature. It falls in line with a Euro-American view of parenting in which distal customs, such as use of cots, swings, prams, and bouncers, are normative (Lachin and Schachter 1974, Keller 2003, Lo 2016, Little, Legare et al. 2018). Following this paradigm, swaddling is yet another 'container' for the infant. In contrast, for some hunter-gatherer groups, swaddling turns infants into a mobile unit and in turn, facilitates a high degree of holding and carrying of the infant (Qiyao 2009). It is unlikely my view would be supported in such a culture. Similarly, many indigenous cultures in North America and throughout northern Scandinavia use a cradleboard swaddling configuration to facilitate both proximal *and* distal care (Chisholm and Richards 2008). After swaddling, infants are strapped to a broad, firm protective frame with a headpiece to provide shade. The cradleboard is used to wear and carry the infant (proximal care) and also to 'park' the infant (distal care). Certainly, proximal and distal caregiving styles are thought to be practiced in differing ratios across cultures. It would be interesting to explore if and how swaddling morphs in utility across cultures, applying the analytical framework of the proximal/distal dichotomy.

My hypothesis, that swaddling promotes and encourages distal care, has several theoretical, methodological, and clinical implications. Theoretically, it marries the conceptual framework of mother-infant synchrony with the distal/proximal dichotomy, and prompts the question: Do distal dyads exhibit less synchronous events, and if so, to what degree? Further, as parental concerns and beliefs are shown to influence caregiving behaviour (as evident in the sociohistorical review), my hypothesis suggests this process is bilateral: certain caregiving behaviours (swaddling) also influence parental beliefs, for example, producing the maternal cognition that the infant does not need to be held because the swaddle is an acceptable facsimile. Just as the social meanings given to infant bodies transform how caregivers handle infants, so they create and transform the relationship between the mother and her infant. Future ethological swaddling studies could test my hypothesis of distal predominance by including proximal and distal observational indicators within their coding taxonomies. If findings are promising, a worrying question is raised: As infants sleeping distally in rooms by themselves are at higher risk of dying than those sleeping proximal to a committed caregiver (Blair et al. 1999; Vennemann et al. 2009; Forste et al. 2001; as cited in McKenna 2016), could infants separated via swaddling be at greater risk of the same fate?

I have argued that swaddling is both separative and transformative. In terms of the proximal/distal dichotomy, swaddling could be considered as the worst of both caregiving styles. On safety grounds, the intervention is incompatible with many proximal caretaking practices such as bedsharing, forcing parents to adopt a distal approach. Then, as physical contact between mother and infant is reduced, mutual engagement shifts to the visual (Lavelli and Fogel 2002). Yet, as the swaddle obscures (even suppresses) a myriad of visual infant cues, it also undermines distal care.

This dynamic is problematic given that distal care contradicts the evolutionary status of humans as a 'continuous contact' species (Shad, 1963, as cited in Stuebe and Tully 2019). From the perspective of evolutionary biology, the 'fourth trimester' is intended to take place on the mother's body, not in an inanimate container. Swaddling therefore prevents infants from occupying "the playing field of the mother's body" (Dervin 2008)(p226). This is of utmost importance considering an infant's wellbeing rests upon whether their mother has the opportunity to 'sense' infant signals and cues and to respond in turn behaviourally and/or physiologically (McKenna, Ball et al. 2007). To successfully accomplish this exchange, infants must have a sufficient repertoire of behaviours "so that interlocking sequences are possible and a smooth-flowing interactive system develops" (Barnard and Solchany 2002)(p16). Indeed, interaction through close and prolonged mother-infant physical contact is vital "not just in terms of psychological development, but also in terms of basic physiological functioning" (Ball and Russell 2012)(p389). One example is 'anxiously attached' infants who tend to have mothers who were averse to close body contact (Ainsworth, 1978, as cited in Trevathan and McKenna 1994). I argue, therefore, that swaddling may interfere with caregiver attachment during a sensitive window of development. Asynchronous interactions with attachment figures during infancy are thought to profoundly impact upon biobehavioural regulation and endure through childhood (Feldman 2012).

Furthermore, as swaddling is primarily a sleep intervention, its implications for nocturnal mother-infant interaction are particularly germane. Sleep and wake states are a product of mother–infant neuroendocrine and neuro-behavioural synchrony (Barry 2020) and reflect infant self-regulation as engineered by the quality of mother-infant interaction patterns (Beebe 2006, Feldman and Eidelman 2006, de Graag, Cox et al. 2012). The biobehavioural literature (see Chapter 4) suggests that swaddling both imitates and deprives the dyad of bidirectional experience, potentially manipulating the role this cue may play in regulating sleep physiology (Korner and Thoman 1972, McKenna 1986, McKenna, Thoman et al. 1993). For instance, swaddling produces constant pressure on the infant's skin and muscles - a form of hyper-touch - whilst acting as a barrier to maternal touch.

1.2 Breastfeeding: cause for caution

Recent research underscores a strong association between breastfeeding outcomes and proximity of the infant to the mother at night (Bailey, Tawia et al. 2020). In this regard, swaddling is a double-edged sword: Visual obscuring of feeding cues means that crying is one of the few behaviours a swaddled infant can adopt to communicate their hunger. In Western industrialised societies, crying is the most commonly reported hunger cue used by mothers to initiate feeding (Gross, Mendelsohn et al. 2016). However, as discussed below, swaddled infants cry significantly less overall, and as swaddled infants cannot engage in physically active feeding behaviour, the intervention may be said to cultivate an environment more compatible with bottle-feeding. In this vein, swaddling has been criticised by midwives who claim it "accentuates the discontinuity of postnatal transition" and "assumes that the continuity of maternal nutrition ends at birth" (Colson 2002)(p61). Similarly, lactation specialists maintain that breastfed infants should not have their hands anchored away from the breast by swaddling (Cadwell 2007). Both sentiments were echoed in my survey data where 'hands out' was the most popular swaddle technique recommended by health professionals.

In reference to the early postnatal days, Tow and Vallone 2009 stress that "the competency of the infant at birth is a biological imperative" for breastfeeding establishment (Tow and Vallone 2009) (p626). Chapter 5 (clinical review) highlighted the fact that, after an unmedicated labour and delivery, unswaddled newborn human infants placed onto their mothers' stomachs will crawl and squirm towards the nipple, guided by smell, and then suckle without assistance (Varendi, Porter et al. 1994, Nissen, Lilja et al. 1995, Varendi and Porter 2001). The same infants will perform an instinctive pattern of 'kneading' hand movements that have been shown to increase maternal oxytocin levels and facilitate milk let-down, a behaviour which continues through infancy (Matthiesen, Ransjo-Arvidson et al. 2001)[27]. It follows that swaddling impedes the adaptive behaviours available to infants at birth, as demonstrated by the breast crawl. In other words, as a physical barrier between mother and infant, swaddling undermines the continuity and postnatal effectiveness of the maternal body as the ideal environment for her neonate. In doing so, the intervention undermines feeding as a relational, interembodied practice (Tomori, Palmquist et al. 2016), placing swaddled infants at a disadvantage in comparison to their non-swaddled counterparts. Those that experience skin-to-skin contact are more successful at establishing breastfeeding and breastfeed for more months (Anderson, Moore et al. 2003, Singh, Khan et al. 2017, Cadwell, Brimdyr et al. 2018, Vila-Candel, Duke et al. 2018, Tosun Guleroglu, Mucuk et al. 2020). Lupton describes this dynamic as "skinship", the relational state created by close physical proximity, touch and intimacy (Lupton 2013) (p40). These factors form an adaptive and bidirectional complex recognised in many non-WEIRD cultures (Bonamy 2016, McKenna and Gettler 2016, McKenna and Gettler 2016, Ball 2019) where infants are attached to their mother's body, in continuous contact with the smell of milk, and always ready to be fed (Morelli, Rogoff et al. 1992, Richman, Miller et al. 1992, Hewlett, Lamb et al. 1998, Hewlett and Lamb 2002, Sansone 2004). Such instinctive behaviour is considered 'controversial' under the Western biomedical model (Van Esterik 2017). Birthed from a marriage of capitalism and industrialisation, detailed in Chapter 3 (sociohistorical review), this authoritative model emphasises the separation of bodies to ensure 'safety' (Ball 2002, Ball 2003, Alexeyeff 2013, Ball, Tomori et al. 2019) with a goal of minimal and eventually no night-time breastfeeding (Tomori 2014, Tomori, Palmquist et al. 2016).

As evidenced in Chapter 7 (lab study), the impact of swaddling upon sleep is interrelated with its impact upon feeding. Swaddled infants wake less frequently. This is problematic for all infants but particularly breastfed infants, as a reduction in feeds affects the bio-behavioural

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[27] However note, in the case of premature infants, swaddling with hands up near the face and midline is believed to decrease disorganized behaviors that could detract from feeding McGrath, J. (2007). "“My Baby Weighs Almost 10 Pounds:” Families and Feeding the Preterm Infant." Newborn and Infant Nursing Reviews **7**: 175-176..

synchrony of the mother-infant dyad, damaging the mother's milk supply. The phenomena of 'arm cycling' gives a possible clue to one of the mechanisms at play. When infants progress from deep to light sleep, their arms begin to wave, or 'cycle' (Gerard, Harris et al. 2002, Richardson, Walker et al. 2010). Scholars argue that this arm movement serves as a natural cue to help wake the infant for feeding (Colson, DeRooy et al. 2003, Fauntleroy 2012). Therefore, when the arms are bound by swaddling, the infant may cycle back into quiet sleep and miss a feeding opportunity. This observation demonstrates how variations in sleep ecology may have substantial consequences for the functioning of maternal lactation biology (Ball 2008, Ball 2019). Infants are efficient at suckling and swallowing during both sleep and awake states (Colson 2010), suggesting that a considerable part of milk intake may occur during sleep for those infants permitted unhindered access to the breast (Rosin 2019). With this discussion in mind, it is therefore concerning that most health visitors in my survey (Chapter 9) did not believe swaddling impacts breastfeeding.

Section 2. The role of swaddling as a womb facsimile

> *"The womb is an ideal calming environment. If you understand this environment, you can recreate it when appropriate to calm your baby, especially during the early weeks when the transition from womb to busy sensory world is the most drastic. Regulating your baby's sensory environment in the first few weeks and months can make the transition smoother and positively effect many facets of his development" (Faure and Richardson 2006)(p21).*

As this quote describes, newborn infants experience a 'transition process' from womb to world; limbs become strong, feeding is established, and sociability begins to develop. In Roman times, infants were not considered full members of the community during this transition period (Graham 2013). A swaddled infant was effectively deemed 'unborn'. In modern times the concept of the 'fourth trimester' links back to this notion of a critical transition period from womb to society. The historical conceptualisation of swaddling as a manmade facsimile of the womb and therefore facilitator of this transition survives to the present day where many believe the pressure of motor restraint mimics the womb environment. The health professionals in my survey (Chapter 9) believed swaddling to be most appropriate for newborns relative to older infants. However, is simulating the womb environment postnatally a good thing?

2.1 Womb-to-world mis-match hypothesis

> *"It's actually common for new babies to resist swaddling. It can make parents think, My baby hates to be wrapped! Of course, you would probably hate to be swaddled, but adults would also hate to live in a womb for 9 months or to drink milk—as their only food—for every single meal, but babies love all of this. Remember, babies don't really need freedom—they need to feel snug and secure like they did in the womb"* (Karp 2020).

"[Through swaddling] an active baby turns into a creature, which is more passive than the foetus ever was" (Frenken 2011)(p238).

In Chapter 4 (biobehavioural review) we considered how womb mimicry through motor restraint produces a phenomenon in animals known as 'squeeze-induced somnolence' (Pickles 2014). After viewing the coma-like state of animals exposed to motor restraint, veterinarians hypothesised that restraint "may resemble the effects of compression of the foetus in the birth canal and lead to inhibition of voluntary activity" (Pickles 2014)(p4).

In that chapter I detailed the similar effects observed in human infants, synthesising a wealth of biobehavioural research. Here, I argue that the evolved biology of the post-natal infant is designed for extra-womb conditions and therefore mimicking the womb environment is unhelpful and possibly even harmful: the 'Womb-to-world mis-match hypothesis'. The world outside the womb provides diverse sensory input that is distinct from that provided by the closed environment of the uterine cavity. I argue that infant physiology has not adapted to remain in tight womb-like conditions post-birth and thus continuation of such conditions is mismatched to infant needs[28].

In Chapter 3 (sociohistorical review), I cited Rousseau's declaration that infants should not exit the uterus only to be placed in other uterus-type restraints. My hypothesis provides a biobehavioural rationale for his argument, based upon my synthesis of the literature that indicates the sensory manipulation of swaddling is mismatched to the evolutionary expectation that infants function in the specific sensory environment of their mother's body. Newborn behaviour, like the breast crawl, provides observable evidence of the neonate as behaviourally distinct from the foetus, with different needs.

[28] An exception to my mis-match hypothesis may present in premature infants. This population are shown to be especially responsive to womb-like sensations because of their immaturity Moller, E. L., W. de Vente and R. Rodenburg (2019). "Infant crying and the calming response: Parental versus mechanical soothing using swaddling, sound, and movement." PLoS One **14**(4): e0214548.. Many medical problems of prematurity are believed related to absence of uterine conditions. My clinical review detailed the many benefits of swaddling pre-term neonates.

Figure 56 Swaddling as a womb facsimile

My proposal is radical in that it challenges the persistent and dogmatic rhetoric that 'physical simulation of the womb calms infants' as illustrated in this section's opening quotes by Faure and Karp. Such rhetoric overlooks the biobehavioural nature of the maternal body as regulatory and responsive in contrast to the artificially 'engineered' constraint of swaddling. For instance, whilst the foetus receives a constant stream of nutrition through the umbilical cord, newborns must not only suckle but also solicit their mother's cooperation in feeding, a process which involves a degree of coordination and initiative. Newborns also have different social capacities than foetuses; as detailed in Chapter 4 (biobehavioural review), they use "intersubjective motor control" 'publicly' for others to view, 'provoking' their response (Trevarthen 2011)(p121).

The full clinical impact of swaddling has not yet been recognised but may be sizable. My analysis provides a framework for future investigation. Considering respiratory impact for example, newborns cannot exchange oxygen and carbon dioxide through their mothers like foetuses. During sleep, periodic changes in body position as a result of newborn startles or 'thrashing' are thought important for airway protection (Thach 2002). Swaddling not only suppresses neonatal startle reflexes but also, the tightness of the swaddle may impact breathing, increasing the risk of apnoea. For example, continued restriction of the diaphragm leads to shallow breathing and an increase in respiratory activity (Kahn, Rebuffat et al. 1992); this can lead to impairment of gas exchange, and result in hypoxia or hypercarbia, which are risk factors for apnoea in young infants (Li, He et al. 1986).

2.2 Swaddle tightness – an evasive variable

Supporting my argument that postnatal motor restraint is not homologous to the restraint provided by the uterine walls, earlier scholars maintained that "intrauterine pressure is not great, and, since the fetus is in a fluid medium, the pressure is approximately equal upon all parts of the body; each part is subjected only to a very gentle pressure" (Dennis 1940)(p208). This raises the question as to what, if any, external pressure is appropriate for full-term neonates? My innovative sensor experiment (Chapter 8) does not answer this question but offers researchers a viable means to explore this important issue. The use of pressure sensors facilitates numerous theoretical and methodological avenues for enquiry. Is it the restraint of movement, or degree of pressure/stimulation, which produces the observed outcomes in swaddled infants? Large-scale behavioural research incorporating calibration of swaddle tightness in comparison with pressure garments may help to answer this question. The sensor can measure pressure differences across different swaddle products at any point on the body. This could enable swaddle products to be specifically designed for different populations (e.g., low birth, premature, NICU patients) and for different purposes (e.g., sensory stimulation, containment, positioning, pain relief).

Calibration of swaddle tightness could have significant implications for parents, researchers, policy makers and health professionals who have so far been limited to describing swaddle tightness in subjective terms. Advice, such as that given by the health professionals who responded to my survey (Chapter 9), that infants should be wrapped "tight enough to reduce the risk of inadvertent head covering" is nebulous without objective criteria. The same problem applies to official guidelines prescribing that caregivers should practice "hip-healthy swaddling", and avoid "tightly" wrapping infants (IHDI 2020). Highlighting swaddle tightness and bringing the topic into public and professional debate is of timely importance. As Chapter 5 (clinical review) illuminated, tight swaddling is associated with Developmental Dysplasia of the Hip (DDH), yet as my survey and other international surveys have shown, DDH is rarely acknowledged by contemporary health professionals.

2.3 Liminality: Is it dangerous to introduce swaddling to older infants?

If newborn infants have not evolved to remain in womb-like conditions, then it stands to reason that older infants would be even less likely adapted to womb conditions. Nonetheless, populists maintain that, "Even if you have never swaddled your baby before, swaddling may still help soothe her" (Karp 2004). Indeed, in terms of routine versus non-routine swaddling, scholars in the 1960s and 1970s recommend swaddling only be practiced 'during episodes of irritability' (Lipton, Steinschneider et al. 1965, Wolff 1966, Brackbill 1971, Giacoman 1971)}. It seems this belief has endured, given that most of the health professionals in my survey (Chapter 9) favoured non-routine swaddling across all infant age ranges. However, in this section I argue that late introduction of motor restraint to infants may disrupt the foundation of the mother-infant dyad with perilous results.

Infant sleep guidelines propose that "Swaddling is safest from birth" (BASIS 2018). Yet, as parent-offspring conflict is expected to increase during the period of parental care, the likelihood of ad hoc interventions also increases (Hiscock 2010). Here, the progression of developmental stages over the first six months can trigger parents to re-examine sleep arrangements (Lau and Hall 2016). For instance, the switch from bed-sharing to cot sleeping may coincide with the introduction of swaddling as a transitionary aid (Stuebe and Tully 2019).

Relevant here is alleviation of infant crying, a dominant cross-cultural and cross-historical motivation for swaddling. In the normal infant developmental trajectory, the phenomena of end-of-the day fussiness and crying begins at around 3 weeks of age, peaking at about 8 weeks, and subsiding by 12 to 16 weeks of age (Brazelton 1962, James-Roberts 2007). A populist response to this normal infant behaviour may be to intervene: "Even normal babies have spells of sickness and crankiness when it is advisable to arrange, for the sakes of all concerned, that they cry less and sleep more" (Brackbill and Fitzgerald 1969)(p180). Certainly, reactive (unplanned) swaddling is likely to result from a situation where sleep deprived parents desperately seek a solution (Lau and Hall 2016, Kommers, Truijens et al. 2017), and indeed, some paediatricians have recommended introducing swaddling at this point (Sparrow and Brazelton 2008).

To my knowledge, only two studies have ever examined both naïve and routinely swaddled infants (Richardson, Walker et al. 2010, Kelmanson 2012). The latter relied upon maternal report and did not introduce swaddling to the naïve infant group. The other studied 27 breastfed infants and found significant differences in outcomes for infants inexperienced with swaddling compared to those routinely swaddled. The authors noted that older infants (3 months of age) naive to swaddling “exhibited decreased spontaneous cortical arousal, similar to responses observed in future victims of sudden infant death syndrome” (p87). Neither study attempted to identify any biobehavioural mechanisms for their findings. Hence in my lab study I aimed to bridge that gap, hypothesising that motor restraint interferes with established bidirectional or reciprocal communications – a key foundation of the mother-infant dyad.

In normal sleep, changes in temperature, respiratory rate, blood pressure, and heart rate regularly require adjustments, particularly during transitions to different sleep states (Tarullo, Balsam et al. 2011). In older infants naive to swaddling, many of the adaptive responses the brain learned before exposure to the intervention cannot be performed in a swaddled state. Most potently, an infant has little ability to carry out postural change or utilize many of their innate reflexes. Furthermore, certain sleep positions and tactile cues co-occur with respiratory and thermal challenges (Lipsitt 1982, Paluszynska, Harris et al. 2004) and the body's normal response to such threat is to perform adaptive postural adjustments or to arouse. Perhaps the most primitive example of this mechanic in infants can be found in the startle reflex which can be triggered in response to respiratory challenge (Paluszynska, Harris et al. 2004). However, swaddling prevents motor activity that would ordinarily turn a startle into a full awakening (Lipton, Steinschneider et al. 1960). In Chapter 4 (biobehavioural review) I termed this The Movement Hypothesis: an infant’s inability to move reduces arousal.

It is worth noting that SIDS has been associated with homeostatic instability (Kinney, Filiano et al. 1995) resulting from the nervous system's failure to mount compensatory adjustments to threat (Harper 2001). The potentially important role of motor movement on the pathway to full arousal is illuminated by data linking processes used in motor activity with the same neural pathway as processes used in arousal from sleep (Sherrington 1973, Thach 2002). Scholars have termed this phenomenon "associative learning of an adaptive arousal response" (Tarullo, Balsam et al. 2011)(p20). Such responses enable an infant to return their body to physiological homeostasis.

All of the above dynamics are managed by the central nervous system, and a central function of the fourth trimester is nervous system maturation (Feldman and Eidelman 2006). I propose that sudden or sporadic manipulation of sensory experience via swaddling may affect nervous system maturation in some infants. My hypothesis therefore suggests that *the process* of habituation is inherently risky, particularly in infants who are beyond the neonatal period.

It is thought that newborns use a different model of habituation to older infants, due to the relative immaturity of the former (Schöner and Thelen 2006). Although neonates are born with a fairly well-developed sense of touch, they are not born with sensory integration. Their nervous system is not yet advanced enough even for the infant to know exactly where they are being touched (Faure and Richardson 2006). This plastic system is then cultivated over time as the infant experiences its environment. Plasticity is arguably strongest during the first postnatal days. Evidence for this can be seen in the fact that Heart Rate Variability changes significantly during this time, exhibiting a brief increase over the initial postnatal period followed by normalization (Oliveira, von Rosenberg et al. 2019).

As the neonatal nervous system develops in synch with touch and movement experiences, the newborn brain begins to form an internal map of the body. Therefore, an infant that experiences free use of their limbs will develop a different 'body map' to infants swaddled from birth (Marshall and Meltzoff 2015). When swaddling is introduced from birth, the habituation process may be less intense, due to the "dramatic experience-dependent plasticity" of the newborn nervous system (Espinosa and Stryker 2012)(p230). In particular, studies have shown high plasticity in the initial stage of infant motor (Held 1965), and somatosensory (Erzurumlu and Gaspar 2012) development.

Unlike newborns however, older infants have a relatively developed nervous system and more functional sensory integration. Their movements are more voluntary, more organised, and are not ruled by reflexes to the same extent as the newborn nervous system (Gordon 1929, Pollack 1960, Futagi, Toribe et al. 2012). The introduction of motor restraint to older infants is an "unusual event" and poses "significant change", terms that have been associated with 'stress' and 'trauma' in both medical and psychological literature (Sadeh 1996)(p686). Likewise, paediatric psychologists have warned that swaddling could cause "a level of distress and resistance among older infants" (Bortfeld, Fava et al. 2009)(p53). Adopting a similar stance, the International Society for the Study and Prevention of Perinatal and Infant Death (ISPID) corroborate the earlier guidance from the Baby Sleep Information Source and recommend it is safest to swaddle infants from birth. Both organizations particularly warn against introducing swaddling at 3 months of age, a time when SIDS risk is greatest (Horne 2020). Furthermore, as mentioned above, non-routinely swaddled infants have been shown to demonstrate higher arousal thresholds (Richardson, Walker, et al. 2010) considered a risk factor for SIDS (Harper and Kinney 2010). More research is required to understand the physiological mechanisms involved during the window of transition from naivety to habituation, including factors that influence the length of the process. Later in Section 3, I offer a theoretical framework that could underpin such research, focusing upon sleep states.

2.4 The Independence Paradox

"Our infants could not, and do not, survive in isolation" (Stuebe and Tully 2020)(p70).

My personal fascination with swaddling originally arose from my interpretation of the intervention as counterintuitive. By effectively disabling the infant, swaddling undermines the very developmental outcome it aims to accelerate--infant independence. I call this 'The Independence Paradox' and base my argument on my synthesis of the swaddling and non-swaddling literature.

Other anthropologists have critically highlighted the irony of those medical scholars that revere infant behaviours (e.g., failing to protest sleep separation, lengthy consolidated sleep) that are actually maladaptive in clinical terms (McKenna 2016). A member of the 'shush and pat' family of practices, swaddling aims to 'teach' infants to self-settle without dependence on being fed or held (Douglas and Hill 2013). In clinical contexts it is prescribed like a drug to treat 'problematic infant sleep', defined by some sources as any sleep that leads to parental intervention (e.g., Morrell & Cortina-Borja, 2002, as cited in Barry 2021).

Swaddling is supported by cultural and political perspectives emphasizing early independence, self-control and self-reliance (Tomori 2014). The practice reinforces the historical notion of infants' 'original sin' and need for self-discipline, reflected in the contemporary zeitgeist as a 'fear of spoiling' the baby (McKenna, Ball et al. 2007). The infant is framed as a dependent being in need of assistance to become independent, autonomous and self-sufficient (Thoman 2006). In Chapter 3 (sociohistorical review), I described the swaddle wrap as both a transitional object and a performative object (Lupton 2013). It is a 'substitute for mother' and a socialisation tool to guide infants through the process of realization that they are separate from their mother and function as a stand-alone unit (Winnicott, 1966, 1971, 1958, as cited in Ross 1982). A populist view argues that infants who sleep through the night increase their mother's own independence, because "independent babies allow for more independent mothers" (Howson, 2018, p. 16 as cited in (Howson, 2018, as cited in Barry 2019)(p16).

The ethnocentric ideal of infant independence is further reflected in policy guidelines that focus on reduced night-waking, little to no co-sleeping, and limited parental contact (American Academy of Pediatrics 2000, Task Force on Infant Sleep and Sudden Infant Death 2000). Here, swaddling has cultural leverage in the juxtaposition of parental expectations and infant biological norms as a sleep management tool.

The utility of swaddling, and other 'sleep aids', dismisses the biological nature of the mother-infant dyad as engaging in mutual physiological regulation of their sleep and arousal architecture (Mosko, Richard et al. 1996, Mosko, Richard et al. 1997). It is argued that the expectation of long sleep and minimal parental intervention may push the limits of infant adaptability (Latz, Wolf et al. 1999). One example of this can be found in infant feeding, specifically the fundamental role of feed frequency in modulating human milk supply (Ball, Ward-Platt et al. 2006, Ball and Klingaman 2008).

Furthermore, as discussed above, alleviation of infant crying is a frequent cross-historical motivation for swaddling, yet introduction of swaddling in response to increased fussiness and crying may interfere with an important step in the development of self-regulatory functions, such as sucking of the hands and rhythmic movement. Swaddling prohibits those behaviours "developed by an individual to manage his or her arousal as opposed to external regulation provided by caregivers and other parts of the environment" (St James-Roberts, Roberts et al. 2015)(p325).

In yet another paradoxical twist, studies suggest that swaddled infants are *more* sensitive to arousing stimuli such as noise (Gardner, Karmel et al. 1992, Lester, Boukydis et al. 1996, Franco, Scaillet et al. 2004, Lejeune, Delacroix et al. 2021) (in Chapter 4--biobehavioural review- I termed this The Enhancement Hypothesis). Based on findings from earlier swaddling studies (Gardner and Karmel 1984, Gardner, Karmel et al. 1992), Demos (Demos 2009) hypothesized that arousal and attention work interdependently as a homeostatic system so that restricted limb movement may *enhance* an infant's intake of new information, strengthening visual attentive resources. Ironically however, due to motor restraint, swaddling places limitations upon infants' ability to respond in a physically dynamic fashion to perceptual stimuli. The intervention is thus argued to result in the infant's "intellectual befuddlement" given that the process is confusing and contradictory (Zornado 1997)(p106).

When their limbs are restrained through swaddling, infants have diminished ability to perform goal-directed movements, or produce observable changes in their environment. I argue that a swaddled infant's unfruitful attempts at interacting with their mother and indeed, with the environment, could result in learned helplessness. Indeed, research "leaves no doubt" that infants are sensitive to such contingency and noncontingency in their environment (Fincham and Cain 1986). 'Noncontingency' in this context, refers to "an organism's belief (implicit or explicit) that no response in its repertoire will bring about an outcome" (p302). This illustrates the paradox of "independence-promoting" (Miller and Commons 2014)(p128) childcare strategies, such as swaddling and use of pacifiers, that seek to delimit parental involvement yet simultaneously restrict infant self-agency. Crucially, swaddling teaches the infant much about their self-agency - they have none, or at least very little.

The Independence Paradox has numerous clinical and theoretical implications. In the clinical domain, the paradox may lead to increased clinical load as if it is applied routinely, swaddling may become a 'sleep association'. Sleep associations created through use of interventions such as swaddling are shown to predict parental report of persistent sleep problems one year on (Morrell and Cortina-Borja 2002). The paradox thus places increased importance upon *style* of swaddling. For instance, infants swaddled with hands up next to their faces (as shown in Figure 57, p275), can self-soothe by sucking on their hands. This enables a degree of self-regulatory agency.

In the empirical domain, more research is needed to understand infants' transition out of swaddling. Do previously swaddled infants take longer to learn 'self-settling'? Does length of swaddling correlate with length of learning to self-settle? Or do swaddled infants settle faster once swaddling is over, compared with never-swaddled peers? One of the components of 'settling' is the direct transition from wake to deep sleep (as per adults) rather than passing through a transitory 20-30 min period of active sleep, which is considered to be more 'immature' (Ball 2021). In the next section I will elaborate on the dynamics of active and quiet sleep, highlighting the immaturity of the former to present a novel theory.

Section 3. Swaddling as maternal deprivation

In this section I build upon my exploration of coerced infant independence by further considering the biobehavioural consequences of disrupting the mother-infant bidirectional system. In contrast to the physical and affective warmth of the mother's body, swaddling has been described as 'impersonal' and 'inexorable' (Barker 2017). At the extreme, some believe the intervention signals "blindness, indifference, or hostility to the child's unfolding needs" (Dervin 2008)(p226). Indeed, absence of human touch has been reported as "one of the most marked of developmental stressors that we can suffer" (Sapolsky, 2008, as cited in Narvaez, Wang et al. 2019) (p1)."

3.1 The role of stress – a novel hypothesis

> *"Immobilization is at the root of most traumas. When that occurs, the vagal system is likely to take over: Your heart slows down, your breathing becomes shallow, and zombielike, you lose touch with yourself and your surroundings. You dissociate" (van der Kolk 2014)(p84).*

In Chapter 4 (biobehavioural review) I outlined my most controversial hypothesis regarding swaddling: That the reduction of arousal and longer sleep observed in swaddled infants reflects activation of the sympathetic nervous system or 'stress response'. I call this my 'Stress Hypothesis'. Supported by a wealth of physiological, evolutionary, psychological and sociohistorical data, spanning over a century, along with my own lab observations, I suggest that swaddling is experienced by infants as maternal deprivation, or even a form of abandonment. Indeed, physiological data show that swaddling impacts infant physiological state in a way inconsistent with the "steady state" proposed by early scholars of swaddling (Lipton, Steinschneider et al. 1960). For instance, as Chapter 4 (biobehavioural review) detailed, compared with non-swaddled infants, swaddling produces a significant increase in heart rate (HR) (Brackbill 1971, Gerard, Harris et al. 2002, Richardson, Walker et al. 2010) and a reduction in Heart Rate Variability (HRV) (Lipton, Steinschneider et al. 1965), both common markers for stress (Kim, Cheon et al. 2018).

What remains unclear however is whether the stress response is triggered by motor restraint *per se* (including the pressure exerted by tight swaddling and/or the degree of novelty), or by denial of interaction with the mother, or by a combination of both. Several studies have shown swaddling to be associated with reduced reciprocal interactions between mother and infant (Bacon, Bell et al. 1991, Cheng and Partridge 1993, van Sleuwen, Engelberts et al. 2007). Numerous studies also show motor restraint to trigger an acute stress response in animals (McCarley and Hobson 1971, Finch, Feld et al. 1978, Kiiatkin and Zhukov 1986, Al'bertin and Golovacheva 2002, Buynitsky and Mostofsky 2009). In humans, a similar shutdown or 'shut-off' response, characterised by 'avoidance' or 'freezing' has been observed in stressed infants exposed to novel stimuli (Fraiberg 1982, Sadeh 1996). It could therefore be argued that swaddling undermines the maternal regulatory role, preventing biological processes central to attachment and stress management, such as the production of oxytocin (Calkins and Hill 2007, Feldman, Gordon et al. 2010, Meaney 2010, Feldman 2012).

Once a stress response is triggered, the situation is exacerbated by the interrelated nature of the infant's vagal tone (the body's ability to relax after stress) with their mother's. Indeed, both systems form a co-regulated relationship (Stone 1971, Feldman, Gordon et al. 2010, Feldman 2012, Yoon, Choi et al. 2019), so that parasympathetic activity (i.e. a relaxed state) increases with synchronistic mother-infant interaction (Evans and Porter 2009). Swaddling prevents behavioural strategies that would otherwise engage this calming parasympathetic response. Infants have an "all-encompassing need for external physiological regulation and emotional support" (McKenna and Gettler 2017)(p4). Swaddling prevents skin-to-skin contact between infant and caregiver, activity shown to regulate arousal levels towards parasympathetic dominance (Hertenstein 2002). Further, the majority of swaddle techniques prohibit infant self-soothing via hand sucking. Such tactile sensory stimulation plays a crucial role in the ability of infants to self-regulate when stressed (Pickens and Field 1995, Field 2010). When unrestrained, infants show an increase of self-touching in situations when interaction with their mother is impaired (Murray 1985, Moszkowski and Stack 2007, Moszkowski, Stack et al. 2009). The younger the infant, the more important touch and kinesis are to self-calming (Durier, Henry et al. 2015).

Paradoxically, infants have been shown to cry 42% less than age-matched unswaddled infants after their first week of swaddling (van Sleuwen, L'Hoir M et al. 2006). If swaddled infants are indeed stressed, as my hypothesis suggests, why would they cry less? I observed a similar discrepancy in crying and fussing between swaddled and unswaddled infants in my lab study (Chapter 7). Not only did the infants demonstrate less fussing and crying bouts on their swaddled night, the duration of these behaviours were also shorter. These outcomes reflect a substantial body of previous data demonstrating the same behaviours (Campos 1989, van Sleuwen, L'Hoir M et al. 2006, Caiola 2007, Karp 2007, Akhnikh, Engelberts et al. 2014, Edraki, Paran et al. 2014). Some authors have assumed this behavioural observation means that swaddling elicits a 'calming reflex' (Karp 2012). However, absence of crying does not necessarily indicate lack of stress. In research exploring sleep training, infants that exhibited reduced crying after a sleep training program were shown to have persistently elevated levels of salivary cortisol (Middlemiss, Granger, Goldberg, & Nathans, 2012, as cited in Barry 2019). In other words, their physiologic stress response remained strong even when their behavioural response (crying) was suppressed. Unfortunately, the link between infant stress and sleep interventions such as sleep training and swaddling, remains grossly under-researched as noted by Ball & Russell on the BASIS website.

"Almost no research has looked at the processes occurring in babies' brains and bodies [during sleep interventions] --we therefore have no way of knowing if a baby or child that is not crying is in fact asleep, or is in what is known as a 'dissociative' state (meaning that the baby has 'withdrawn' in response to the stress of being left alone with no care-giver response and has behaviourally / neurologically 'shut down'). If the baby who has become quiet following sleep training is indeed asleep, is their sleep 'normal' or is it different to that of babies who have not undergone the process?" (BASIS 2021).

Certainly, sleep and wake states are involved in self-regulation. Exposure to stress (whether acute or chronic) can have pronounced effects on the sleep architecture of both animals and humans (Van Reeth, Weibel et al. 2000). Adjustments in sleep pattern are commonly seen following stressful experiences/events (Descamps and Cespuglio 2010). Furthermore, concern has been voiced that "mechanical aids" such as swaddling contribute to "keeping the baby in a kind of benign coma" (Lancy 2007)(p2) or "a zombie-like state" (Ball 2020)(p158). In this vein, scholars postulate that longer infant sleep is an indication of nervous system immaturity rather than a healthy biobehavoural response. Specifically, by prolonging sleep, swaddling may slow the maturation of the nervous system (Frenken 2011). This raises a critical question, is it possible that early sleep consolidation is not optimal, and that night waking serves a role in infant neurodevelopment? (McKenna and Ball 2010).

Of additional concern is my observation that infants exhibit dissociative behaviour while swaddled, akin to behaviour seen in solitary sleeping infants, e.g., gaze aversion, fewer feeds, less verbalisation (Richard, Mosko et al. 1996). Overwhelmed infants in noisy, brightly lit neonatal nurseries are shown to adopt a similar 'defensive', dissociative state (Tronick, Als et al. 1979). In fact, my lab data corroborate previous findings demonstrating that when faced with social disengagement, infants respond with withdrawal (e.g., the Still-Face paradigm; (Brazelton 1973, Tronick, Als et al. 1978, Papoušek and Papoušek 2002). The infants in my study made significantly fewer rooting attempts when swaddled than when unswaddled, and this reduction in feeding attempts is possibly a symptom of the stress response. In animal studies, 'restraint stress' is associated with decreased motivation to eat (Wang, Charboneau et al. 2002). Likewise, in humans, acute stress is associated with feeding suppression (Rabasa and Dickson 2016).

Poignantly, my lab data demonstrated that, when swaddled, infants demonstrated significant preference for facing away from their mother (with the reverse being true when unswaddled). 'Head turned away' is categorised as 'disengaging' behaviour by tools of infant wellbeing assessment (NCAST 1990, White and Bryan 2002). In this sense, looking away serves as a "cutoff mechanism" (p632) and illustrates "attachment resistance" (Margolis, Lee et al. 2019)(p10). Scholars have observed a prevalence of gaze avoidance in scenarios where an infant's "human partners fail in their protective function and he is exposed to repeated and prolonged experiences of helplessness" (Fraiberg 1982)(p614). Studies show infants engage in gaze avoidance following a sudden and unexpected separation from their mother (Papousek and Papousek 2002, Salomonsson 2016), behaviour believed to be an attempt at self-regulation and adopted when infants are feeling overwhelmed (Koulomzin, Beebe et al.

2002, Faure and Richardson 2006, Durier, Henry et al. 2015). This is especially problematic if, as proposed above, swaddling forces a distal caregiving style - a baseline characteristic of which is interaction through the visual sense. Spitz, one of the first researchers who used direct observation of infants as an experimental method, coined the term 'anaclitic depression' to refer to the characteristics of human infants deprived of their mothers (Spitz 1945, 1951, as cited in McKenna 2016)(Spitz 1945, 1951, as cited in McKenna 2016). These characteristics include withdrawal, characterized by "the infant refusing to engage in any and all interactions" (Spitz 1945, 1951, as cited in McKenna 2016)(McKenna 2016)(p208). In video footage capturing one infant's response to maternal separation, the infant did not scream when weeping, but only moaned (Spitz and Wolf. 1947).

3.2 Implications of stress hypothesis

In the Biobehavioural review I introduced 'polyvagal theory', a hypothesis created by Porges and colleagues to suggest a basis for the 'fight, flight or freeze' stress response (Porges 2007, Porges 2009, Porges and Furman 2011). To my knowledge, polyvagal theory (PT) has not previously been applied to swaddling, nor have concepts from animal and human swaddle studies been integrated. Admittedly, PT has been criticised for overemphasizing the role of the vagus nerve in determining between freezing and other fear responses (Johansen, Tarpley et al. 2010, Roelofs 2017). While the vagus nerve undoubtedly plays a role in transmitting and assimilating fear-related signals between the brain and the rest of the body (Bennett 2000), there is no evidence that it controls whether a freeze response is triggered or not. Nonetheless, I defend my stress hypothesis as rather than relying on PT, my hypothesis cites it as a possible explanation for a number of here-to-unexplained physiological and behavioural responses commonly observed in swaddled infants. I am less concerned with the vagus nerve per se, and more with the biobehavioural mechanisms of fear and threat perception. These mechanisms potentially include a large number of brain structures (e.g., the amygdala) including, but not limited to, the vagus nerve.

By synthesising available evidence into a coherent stress theory, my work progresses cross-disciplinary thinking on this topic. In the theoretical domain, my work incorporates evolutionary, neuroscientific and psychological lines of thought. It provides support for PT and refutes Karp's 'calming reflex' hypothesis (Karp 2012). PT expanded on the traditional view of stress as a dichotomous fight/flight response by adding a third response: 'freeze' - a form of physiological immobilisation or 'shutting down', not calming as Karp would propose. Likewise, my stress hypothesis looks beyond the effects of 'fight or flight' and positions maternal regulation as central to stress/arousal processes.

Clinically, my hypothesis indicates a need for radical strengthening of clinical guidelines. Scholars have suggested the existence of a sensitive period for early care environment programming of stress physiology. This window extends from preconception to early childhood (Hochberg, Feil et al. 2011, McLaughlin, Sheridan et al. 2015). Although early exposures to stress are known to shape the functioning of stress-response systems (Morgan, Horn et al. 2011, Miller and Commons 2014), to date, there are no studies examining the stress response in the context of swaddling.

Section 4. Quiet Sleep (QS) rebound hypothesis.

> *"If mature sleeping involves arousal and resettling, as Anders et al and others have found, there is a need for theory-guided research into how the ultradian, circadian, and homeostatic systems that regulate sleep waking develop during this early period" (St James-Roberts, Roberts et al. 2015)(p328).*

In this section I answer the call from St James-Roberts and colleagues by exploring the potential homeostatic systems that regulate infant sleep. I draw upon aspects of my stress hypothesis to propose a systems theory that explains the potential habituation process involved in swaddling. This novel hypothesis will attempt to account for the observed discrepancies across swaddle study findings. Based upon my synthesis of swaddling and non-swaddling literature (Chapters 2-5), and my lab study results (Chapter 7), I suggest the habituation process in swaddled infants may be illustrated firstly by an increase in active sleep (AS), followed by a compensatory rebound of quiet sleep (QS). I call this, the 'QS rebound hypothesis'.

Infancy is a time of rapid growth and development. The human neonatal brain comprises only 25% of its adult volume (Martin, 2007, as cited in Stuebe and Tully 2019). As mentioned above, the period from preconception to early childhood is thought to be the most critical window of development. During this period, infants are "biologically susceptible to context" (Stuebe and Tully 2020)(p68), from subtle environmental cues to more severe ones (Horne 2000, Hochberg, Feil et al. 2011). Interestingly, "extremely premature" infants show faster maturity of their sleep-wake cycles than their term counterparts (De Beritto 2020)(p84), highlighting the powerful impact of the biopsychosocial microenvironment on sleep cycle development.

Infant brain development and function is known to be influenced by sensory stimuli, so that brains exposed to different environmental sensory events are "sculpted" in very different ways (Kolb and Gibb 2011)(p265). Even a singular environmental challenge may elicit a physiologically adaptive response. In the context of mother-infant interaction, this has been demonstrated by the classic Still Face Paradigm. In this experimental procedure, mothers were instructed to be unresponsive to their young child's signals (Tronick, Als et al. 1978). Studies from this paradigm have repeatedly and robustly demonstrated a dramatic response of the infant sympathetic nervous system when confronted with an unpredicted unresponsive mother (Mesman, van Ijzendoorn et al. 2009). As explained above, because attachment is crucial for survival in both humans and animals (Bowlby 1969), any disruption of the attachment relationship can be experienced as a serious threat (Sadeh 1996)(p688). In scenarios of threat, the resulting activation of the stress response increases glucose turnover rates to prepare for a fight or flight response (Marriott 1994, Hane and Fox 2016); however, in environments of continuously poor maternal caregiving, there would be no adaptive advantage to repeated activation of stress physiology, as this would be metabolically costly (Preiser, Ichai et al. 2014). To address this problem, the phenotype has developed the capacity to habituate.

4.1 What is Habituation?

Habituation is the process of learning from and responding to the environment leading to habit formation (Zuo, Panda et al. 2017). The habituation mechanism is demonstrated when an organism progressively decreases its responsiveness to a stimulus. The process is adaptive in that it optimizes the organism's likelihood of detecting and assessing the significance of a stimulus in future encounters (Eisenstein, Eisenstein et al. 2001). Without the ability to habituate, the organism would be over-sensitive to unimportant stimuli, thus wasting attentional resources and possibly missing significant stimuli. In the medical realm, rate of habituation is thought to indicate an infant's capacity to overcome physiological demands in order to attend to his environment (Tronick, Als et al. 1979).

The complex nature of habituation can be understood through systems theory. Here, a system is characterized by a group of parts that interact to form a coherent whole. Systems often have feedback loops, which occur when outputs of a system return as inputs. Changes in one component of a system affect other components as well as the overall entity (Adams, Hester et al. 2013). The process of habituation is triggered when an organism is confronted with a change in the environment. In response, the organism demonstrates the orienting reflex - an increase in arousal. Thought to be mediated by the older, more primitive structures of the central nervous system, this process amplifies the activity of the stimulus-response pathway (Brackbill 1971). With repeated introduction of the same stimulus, a feedback loop is created and the orienting response gradually decreases in intensity until it eventually ceases (Sokolov 1969). Heart rate is one of the primary measures of habituation. Here, the most common initial response to a novel stimulus is that of HR acceleration as part of a defensive reaction (Tronick, Als et al. 1979). Thus pre-stimulus heart rate is inversely correlated with heart rate at the point of habituation (Bridger and Reiser 1959, Steinschneider, Lipton et al. 1966).

4.2 Sleep as an Adaptive Response?

As I discussed in Chapter 4 (biobehavioural review), infants calibrate their physiology based upon a combination of proprioception, other perceptual systems and maternal contact (Rochat and Striano 2000)(p518). In the context of swaddling, habituation occurs when the infant's somatosensory system undergoes orientation to the sensation of being swaddled. Evidence suggests that aspects of sleep play a prominent role in habituation and that this relationship is bilateral (Rasch and Born 2013, Vyazovskiy, Walton et al. 2017, Tempesta, Socci et al. 2018). In fact, the sleep cycle is not pre-programmed as was once thought, rather, environmental cues influence the organization of sleep cycles. In turn, sleep is not a period of passivity, rather, it is a critical context for sensory processing and learning (Del Rio-Bermudez & Blumberg, 2018; Del Rio-Bermudez, Kim, Sokoloff, & Blumberg, 2020, as cited in Sokoloff, Hickerson et al. 2020). Indeed, recent medical scholars have defined sleep as "a time of enhanced neurological function and physiologic activity" (De Beritto 2020)(p82). Despite appearing somnolent, many physiological and neurological processes are occurring during infant sleep. State-of-the-art technological advances are gradually lifting the veil, illuminating a growing number of distinctions between infant and adult sleep. For instance, Mitra et al. (2017) found functional magnetic resonance imaging (fMRI) of sleeping six month olds to most closely resemble that of awake adults (Mitra et al., 2017, in Barry 2020).

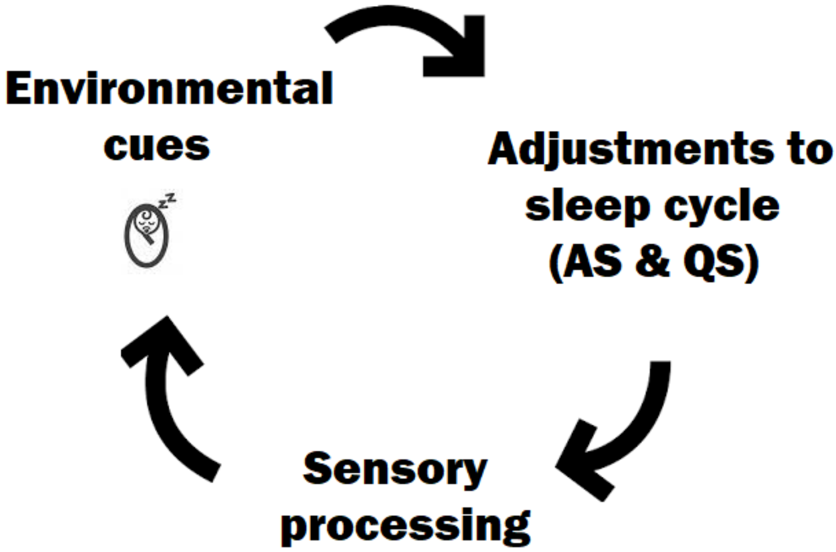

Figure 57 The potential role of sleep in habituation

To explain my QS rebound theory, there are two key components. The first lies in the role of active sleep (AS) as a driver of habituation. AS is thought to facilitate assessment (sensory processing) of stimuli (Pearlman 1979, Franklin and Zyphur 2005, Graven and Browne 2008) and to promote neural adaption through synapse formation and pruning (Roffwarg, Muzio et al. 1966, Denenberg and Thoman 1981, Mirmiran and Ariagno 2003). Evidence from animal studies suggest that such learning in response to a novel stimulus occurs in both awake and AS states, whereas no new associative learning occurs during QS (Maho and Bloch 1992, Hennevin, Hars et al. 1995). Studies have found rapid habituation to occur if a novel tactile stimulus is administered during AS rather than QS (McNamara, Wulbrand et al. 1997, McNamara, Wulbrand et al. 1999). The result of habituation is reflected in cortical storage of information about a stimulus (Tronick, Als et al. 1979), and AS is found to enhance the integration of new information (Cai, Mednick et al. 2009). I therefore propose that habituation to a novel stimulus is driven primarily by AS. In other words, the increase in AS seen in naïve infants is a component of the orientating response, sharing, as it does, an increase in arousal (e.g., heartrate acceleration).

Following this view, AS (or REM sleep in adults) is activated as a way to process stressful stimuli, "helping remove emotional stress and other effects" (Drews et al. 2020, as cited in Barry 2021)(p197). As argued above, the novel nature of swaddling is experienced as a survival threat and therefore a stressful stimulus. Numerous animal and human studies have observed that stressful situations induce increased sleep, particularly AS (Suchecki, Tiba et al. 2012). The potential adaptive value of adjustments to sleep patterns is demonstrated in human studies involving individuals exposed to a threatening or traumatic event. Those who exhibited long episodes of REM sleep did not develop post-traumatic stress disorder, whereas those who had short, interrupted episodes of REM sleep developed the disorder (Mellman et al, 2007, as cited in Suchecki, Tiba et al. 2012). In other words, AS appears to help organisms to process stress. The vagal nerve continuously responds to both the internal needs of the infant and the external demands of the environment in a trade-off between maintaining homeostasis and effectively responding to environmental stressors (Lang-Porter 2001). So we could argue that when a naïve infant is swaddled, a stress response is activated, and stimulation of the sympathetic nervous system pushes the infant into AS. Yet, as infants < 6 months old have an immature vagal tone, the ability of their nervous system to return to homeostasis after a challenge is weaker (Goh 2017). Thus, my stress hypothesis is interwoven with my QS rebound hypothesis, the latter focusing on sleep states.

Although radical, both hypotheses are supported by recent evidence suggesting the stress and sleep systems are interrelated:

> *"The sleep–wake system is immature at birth and develops in parallel with the hypothalamic–pituitary–adrenal axis, a biological stress system of which the end product is cortisol. Perturbations in one system during infancy can maladaptively influence the maturation of the other system, leading to lasting sleep and cortisol system dysregulation" (Tuladhar, Schwartz et al. 2021).*

My hypotheses are also supported by studies of maternal deprivation, and by swaddle studies in which time spent in AS significantly increased (Brackbill 1973, Gerard, Harris et al. 2002)[29], including my own lab data involving swaddle-naïve infants. As I discussed in the literature review, infants are reliant on maternal regulation of their sleep and arousal architecture (Mosko, Richard et al. 1996, Mosko, Richard et al. 1997, Feldman, Singer et al. 2010, Feldman, Magori-Cohen et al. 2011, Feldman 2012, Yoon, Choi et al. 2019). Swaddling, which serves as a physical barrier between infant and mother and a visual barrier between mother and the infant's body, is a form of maternal separation, and infants separated from their mothers have shown increased AS (Morgan, Horn et al. 2011). Moreover, the action of swaddling in preventing or minimising the hypnagogic startle may further undermine the transition to QS.

The second key component of my QS rebound theory rests upon what is known as the Homeostatic Hypothesis (Horne 2000, Tononi and Cirelli 2014). According to this idea, QS may play a later secondary role in the habituation sequence after AS. Here, QS brings cerebral rest following an over loading of sensory systems (Ephron and Carrington, 1966, as cited in Horne 2000) and has restorative properties (BASIS 2020). The habituation process in swaddled infants may be illustrated firstly by an increase in AS, and later followed by a compensatory rebound of QS. Further, because QS *follows* habituation, the infant continues with QS predominance indefinitely.

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[29] These two studies, like the vast majority of swaddle studies, did not declare whether the participants were naive to swaddling at the time of the study.

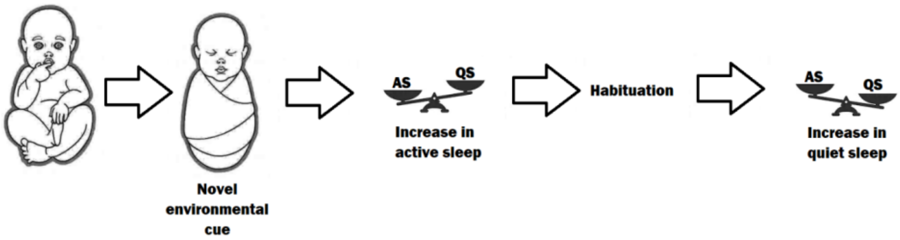


Figure 58 My quiet sleep rebound hypothesis

The chain begins when AS excites the cerebrum, facilitating assessment of the novel situation through dreaming. However, it would be maladaptive for the infant to continue responding with energy intense AS each time they are swaddled. The metabolic demands of AS sleep, as measured by oxygen and glucose metabolism, are significantly greater than during QS and can even exceed energy use during wakefulness (Hobson, Pace-Schott et al. 2000). Thus, a homeostatic outcome of QS rebound is to preserve energy. Such a shift in sleep pattern has been shown to engage restorative process that compensate for stress overshoot (Descamps and Cespuglio 2010). This tipped-scales effect forms the essence of my QS rebound hypothesis. It aligns with the Homeostatic Hypothesis in that the goal of the system is to ensure the tonus (i.e., constant low-level activity) of the cerebrum stays within certain limits — "cortical homeostasis" (Ephron and Carrington, 1966, as cited in Horne 2000)(p777).

Importantly, making continuous adjustments to one's biobehavioural response would be a physiologically costly endeavour and therefore plastic traits are not always favoured over fixed traits (Rickard and Lummaa 2007). Both plasticity and habituation share the ultimate aim of internal stability and thus seek to prevent the sensory system from becoming "flooded with irrelevant sensory input" (Eisenstein, Eisenstein et al. 2001)(p252). By learning to calm the nervous system (increased QS), the infant habituates to match a predicted future environment of continued motor restraint.

4.3 Potential Consequences of QS Rebound

Scholars have drawn attention to the potential of "pathological plasticity" wherein plastic changes in the brain turn out to be maladaptive (Kolb and Gibb 2011)(p271). The association of swaddling with a less demanding infant is a primary motivator of caregivers. Yet prolonged periods of deep sleep do not reflect any behaviour previously experienced in the evolutionary lineage of infants.

There are many reasons why this trajectory may lead to potential pathology. Firstly, extended QS conflicts with the infant's biological need to wake periodically and feed frequently, behaviours rooted in the evolutionary legacy of the species. Infants require frequent feeding to thrive. Secondly, disruption of sleep cycles during early infancy has shown to significantly interfere with sensory development (Penn and Shatz, 2002, as cited in Graven and Browne

2008). This is because the endogenous stimulation provided by sleep cycles is needed to form the basic architecture of the neocortex, the part of the brain that processes signals from the sensory organ (i.e., ear, eye, etc) (Graven and Browne 2008). Last but not least, prolonged QS is associated with a greater risk of SIDS, likely due to impairments in arousal (Richardson, Walker et al. 2010).

Summary

The QS Rebound Hypothesis illustrates how interaction between certain environmental cues and infant responsiveness could lead to maladaptive outcomes. Yet the interplay between swaddling and sleep state outcomes has not been sufficiently researched despite two systematic reviews highlighting the need for this data (van Sleuwen, Engelberts et al. 2007, Dixley 2015). It is hoped that the QS Rebound Hypothesis may reinvigorate debate on this topic. As well as neglecting sleep architecture, the vast majority of swaddle studies have failed to distinguish between infants naive to the intervention and those habituated to it. It is thus unsurprising that this field of research is characterised by inconsistent findings, with some studies associating swaddling with increased QS (Franco, Seret et al. 2005, Meyer and Erler 2011), and others associating swaddling with increased AS (Brackbill 1975, Gerard, Harris et al. 2002). My QS Rebound Hypothesis acknowledges the powerful role of habituation in shaping infant sleep outcomes and uses this system to explain the divergence in outcomes across swaddle studies. My hypothesis is the product of a theoretical attempt at integration. Future research may use this framework as a starting point for targeted and direct examinations of sleep architecture in swaddled infants longitudinally. More research is required to understand the physiological mechanisms involved during the window of transition from naivety to habituation, including factors that influence the length of the process. Indeed, it may be the *process* of habituation that is inherently risky for some infants.

Section 5. Swaddling as a tool to negotiate trade-offs: A life history explanation

> *"In some circumstances the 'least worst' trade-off may be the best available" (Wren, Launer et al. 2021)(p287).*

In Chapter 2 (evolutionary review) I highlighted the contested nature of motherhood and mothering behaviour and briefly introduced the topic of 'trade-offs'. In this final section I will expand on this by explaining in more detail how and why swaddling is applied as a tool to negotiate trade-offs. I do this against a backdrop of biomedicalization and scientific motherhood.

In the early postpartum period, mothers negotiate significant physical, emotional and social shifts in their biobehavioural environment (Stuebe and Tully 2020). Breastfeeding mothers are thought particularly at risk of 'post-partum fatigue (PPF)' and 'infant-related sleep disruption (IRSD)' (Volrathongchai, Neelasmith et al. 2013, Henderson, Alderdice et al. 2019, Ball, Taylor et al. 202,0 as cited in Ball, Taylor et al. 2020). Symptoms include a decreased capacity for physical and mental activity, a persistent lack of energy, and impairments in concentration and attention (Aaronson, Teel et al. 1999, Chau and Giallo 2015, Giallo, Gartland et al. 2015). Attempts to ameliorate PFF and IRSD may result in a mother aiming to balance infant needs (contact, breastfeeding) with her own requirements (sleep) by use of an infant care tool such as swaddling.

Life history theory maintains that organisms are driven to prioritise resources based on predicted costs and benefits over their lifespan (Tully and Ball 2013). When making caregiving decisions, mothers consider their own energetic needs for growth and maintenance versus energy she might invest in reproduction, including parental investment - present and prospective (Borgerhoff Mulder, 1992, as cited in Volpe, Ball et al. 2013). In this way, humans are selected to balance maternal investment across current and future offspring. If maternal investment impedes the condition of the mother, then it is biologically more beneficial to the mother to limit the costs of investment in current offspring and conserve herself for future fertility (Ellison 2003). Heavy maternal investment is actually a sociohistorical construction (Stuebe and Tully 2020).

Indeed, for humans, the cultural and the biological intersect to determine parenting behaviour (Bowlby 1969, Insel 1997, Fleming, O'Day et al. 1999, Papoušek and Papoušek 2002). Parental investment is both biologically and culturally based, and women are the main caregivers by default throughout pregnancy and lactation, and then are assigned the role of the main caregiver throughout childhood and adolescence, leading to greater responsibility for childcare (Vazquez Vazquez 2020). Yet frequently, the demands of contemporary adult life mismatch with evolutionary programmed infant behaviour and with what evolution has prepared mothers to cope with (Wren, Launer et al. 2021). Mothers in industrialised societies, for instance, must balance investing in infant care with investing in waged employment and domestic activities. Both options enhance fitness, the former by enhancing infant survival whilst the latter benefits existing children and other family members (Ball and Russell 2012, Kramer and Veile 2018). A woman today may be the sole carer for her children, with little community support available, and in poorly paid employment. Perception of everyone's needs, familial influences, and resource availability and accessibility intersect to nudge parents towards particular 'trade-offs' (Lau and Hall 2016). Swaddling, may work 'like a drug', 'switching off the baby' (Frenken 2011) and this allows the mother to invest less energy in her infant, and to conserve her physical and mental resources.

4.1 Scientific motherhood and the biomedicalisation of infant care and research

In the early 20th century, a new hyper-medical zeitgeist emerged that would undermine women's confidence in their mothering abilities and "erode or diminish" maternal agency (McKenna 2016)(p223), arguably making them more receptive to interventions. This era saw the establishment of UK health visiting via the Notification of Births Act. The legislation, along with the conversion of midwifery to a trained occupation, invited the "medical gaze" into the homes of families (Wright 1987)(p109). Women were told they needed to follow the instruction of scientifically-informed medical experts and without this direction they were dangerous to their children's health (Apple 1995).

This message of scientific motherhood was necessary to facilitate a switch from infant care as a purely domestic preoccupation to infant care as a biomedical endeavour, policed by experts. As discussed in Chapter 3 (sociohistorical review), this dominant Western narrative reframed infant bodies as discrete, asocial biological bundles to be measured, monitored and managed (Wright 1987)(p109). To date, the literature and guidelines are predominantly informed by this model (Mileva-Seitz, Bakermans-Kranenburg et al. 2017). The cultural biomedicalization of infancy and infant sleep is reflected in the methodology of infant sleep research over the past 30 years. The findings of my systematic review (Chapter 6) show this clearly. The majority of studies were conducted by researchers situated within the discipline of Medicine, and most studies were theoretically deductive rather than inductive; this biomedical approach relies upon presumptions and predetermined scoring criteria and serves to problematize and pathologize variations in sleep that do not meet those criteria (Ball, Tomori et al. 2019).[30] All studies featured cameras in fixed positions, largely reflecting Western biomedical recommendations for solitary static sleep (Ball, Tomori et al. 2019). Further, a smaller percentage of inductive studies were conducted in the home setting despite being the most naturalistic setting. Also of note is the choice of variables. When coding sleep states, several studies employed polysomnography (PSG) in preference over video - yet the sheer amount of polysomnography equipment that must be attached to the infant means normal infant behaviours are affected and normal caregiving activities are hindered. Similarly, my review revealed a flux of automation methods, a form of 'technoscience', that removes the human interpretive aspect of research. The sum of these findings illustrates the increasing global dominance of Western biomedical conceptualizations of sleep, and that infant sleep science is influenced by Euro-American cultural assumptions (Ball, Tomori et al. 2019). A good example of this dogma is reflected in the phenomena of medical infant care 'Guidelines'.

4.2 Creating and Disseminating Guidelines: Avoiding the Research Practice Gap

> *"For every complex problem, there is an answer that is clear, simple and wrong" (Barry 2020)(p26).*

Guidelines reflect the tendency of medical authorities to reduce complex issues into simple one-size-must-fit-all, sweeping generalizations (McKenna 2014, Tully, Stuebe et al. 2017). This problem has been termed 'the research-practice gap'. The World Health Organisation (WHO) acknowledge the prevalence of this issue and trace it to the initial stages of guideline creation, citing, "Whereas the researcher takes an analytical approach to thinking, clinicians are more likely to take an intuitive approach" (World Health Organization 1997)(p4). For clinicians saddled with "the value-saturated" task of making a decision about an individual patient with multiple characteristics, guidelines can seem reductive (World Health Organization 1997)(p4).

The WHO use the phrase "desired health outcomes" to highlight the link between the guideline and the intended end result (World Health Organization 1997)(p4). Deciding what constitutes a 'desired health outcome' is inherently value-based, reflecting larger concerns of the biomedical and political elite (Rosenfeld, Shiffman et al. 2013). In practice, clinicians,

[30] Part of the 'Infant body as uncivilised' cultural construct (see sociohistorical chapter).

home visitors, and other practitioners are inclined to assess either the needs of the infant or the needs of the mother (Tully, Stuebe et al. 2017). This approach overlooks the physiologically and psychologically interconnected nature of the mother-infant dyad (Tully and Ball 2018). In this context, swaddling is considered for the mother's benefit, as a "short-term domestic practice adopted in response to real-world conditions" (Ahn, Yang et al. 2020)(p85).

Creating and disseminating guidelines without considering real world parental expectations, experiences and challenges is counter-productive (Moon and Fu 2012). A complex challenge presents tension between promoting maternal adherence to guidelines on one hand, and supporting mothers to make informed decisions on the other hand (Tully, Stuebe et al. 2017). For example, it is known that mothers assess potential costs and benefits of night-time infant care strategies within margins of risk, yet this concealed process is overlooked by present risk-reduction guidelines and their affiliated campaigns (Volpe, Ball et al. 2013).

In contrast, anthropologists suggest that guidelines should be based upon the outcomes that matter most to patients (Tully, Stuebe et al. 2017). Accordingly, as mothers are influenced by their sociocultural world, the Western cultural assumption of consolidated sleep may lead them to view any night waking as a problem to be addressed. Thus, for many mothers, 'good' infant sleep is the desired outcome. This target is medically characterized as independent sleep onset, longer consolidated sleep periods, self-soothing at night, and more sleep per sleep–wake cycle (Schwichtenberg et al, 2013, as cited in Barry 2020)(p17). Against this backdrop, guidelines can appear nonsensical to many mothers, failing to align with their lived experiences and constraints. Indeed, policy makers often neglect the intensive nature of infant-care as necessitated by infants' biological needs, the breadth of which require substantial and sustained investment by caregivers, usually mothers (Tully, Stuebe et al. 2017).

The one-size-fits-all nature of guidelines is particularly unhelpful in the postnatal domain which is compounded by mothers' individual health, social and emotional challenges. Such vulnerabilities influence how mothers interpret and react to the task of parenting (St James-Roberts 2013). In the US for instance, absence of paid maternity leave results in 23% of employed mothers returning to work within 10 days of giving birth (Tully, Stuebe et al. 2017). Such conflict between mothers' reproductive and productive lives has created an imperative to get infants to 'sleep through the night' (Tomori 2014). Unsurprisingly, 'sleep and fatigue' has been identified as one of the core interrelated health domains of the postnatal period, alongside mood and emotional wellbeing, infant care and feeding, and physical recovery (Tully, Stuebe et al. 2017). When mothers struggle to manage infant behaviour in ways compatible with safe sleep guidelines, they are shown to reframe those guidelines as suggestions with room for individual interpretation (Lau and Hall 2016). Discrepancy between ideal and reality can lead mothers to employ "whatever strategies they found effective to induce sleep" (p2820). In this context, a reductionist or abstinence-only approach to swaddling may set the bar too high for some families, undermine parental confidence and lead to parent-professional alienation and other unintended consequences like breastfeeding cessation (Altfeld, Peacock et al. 2017, Ball 2017). Overly-simplistic guidelines can "drive a mother away from her own feelings and needs in a deleterious way" (Sansone 2004)(p2).

Rather than adopting a 'risk elimination' approach which would outright discourage swaddling, medical anthropologists recommend a 'risk minimization' approach, in which information is given to caregivers facilitating informed choice (Ball 2017). For example, the U.S. National Action Partnership to Promote Safe Sleep aims to move from "campaigns to conversations" (NAPPSS, 2017, as cited in Altfeld, Peacock et al. 2017), and the AAP elaborate that practitioners should include swaddling in conversations about safe sleep practice (Kennedy and Glassy 2013, Task Force On Sudden Infant Death 2016). From a transactional viewpoint, such conversations should occur well before a mother may require the intervention. This is because, at population level, swaddling is often applied in a reactive way. Indeed, there are three parental approaches to the use of interventions like swaddling: Those parents that plan to adopt an intervention during pregnancy, those that only consider the intervention after the birth, and those that adopt the intervention in response to their infant's early behaviours (Hiscock 2010). The latter two types of reactive (unplanned) swaddling are likely to result from a situation where sleep deprived parents are desperately seeking a solution. On the other hand, planned swaddling represents a predetermined choice to swaddle, based on parenting values (Lau and Hall 2016). The difference is important in that adverse outcomes, such as feeding problems and SIDS, are more likely to occur when parenting decisions are made reactively (Vennemann et al, 2012, as cited in Lau and Hall 2016). For almost a decade in the U.S., the possibility of swaddling has been factored into prenatal education. WIC (Women, Infants, and Children) clinics teach swaddling as an integral aspect of infant care (McGrath, Thillet et al. 2007) and at postnatal discharge, where instructions typically feature a list of self-care and infant care skills, including how to swaddle (Wagner, Bear et al. 2011).

Recently, there has been a shift in the theoretical approach adopted by clinicians in dealing with families in both the United States (Rapley 2002, Gordon, Rowe et al. 2015, Altfeld, Peacock et al. 2017, Mileva-Seitz, Bakermans-Kranenburg et al. 2017) and the United Kingdom (Rosen-Carole, Hartman et al. 2015, Ball and Blair 2017, UNICEF UK 2018). Over the past decade, UNICEF implemented an international accreditation scheme known as 'the Baby-Friendly Hospital Initiative'. The scheme is designed to evaluate clinical environments based upon adherence to three basic evolutionary principles of postnatal care: mother–infant skin-to-skin contact upon delivery, encouragement of breastfeeding, and 24-hour rooming-in (Unicef UK Baby Friendly Initiative 2001). Although the initiative has made some progress in re-aligning WEIRD clinical settings with the evolved needs of mothers and infants, lack of definitive evidence about its pros and cons prevents the incorporation of swaddling in the UNICEF postnatal guidelines.

4.3 Swaddling: A Clinical Guidance Tool

> *"One of the biggest challenges facing the NHS is cultural. Specifically, the relationship between the public and the NHS, and between patients and the staff who care for them, needs to be transformed" (Ham, Charles et al. 2018).*

> *"Parents who wish to swaddle should be informed how to do this correctly to reduce the risk" (The Lullaby Trust 2019) (p30).*

Mindful of the reductive and over-simplified 'one-size-must-fit-all' nature of guidelines, the resulting 'research-practice gap', and problems of maternal adherence discussed above, I have created a novel tool to facilitate patient-led health promoting discourse regarding swaddling. Situated within anthropological theoretical frameworks of health trade-offs and parental-investment theory, I designed this conversational tool to enable mothers and their health practitioners to safely negotiate trade-offs between parent and offspring needs with respect to swaddling.

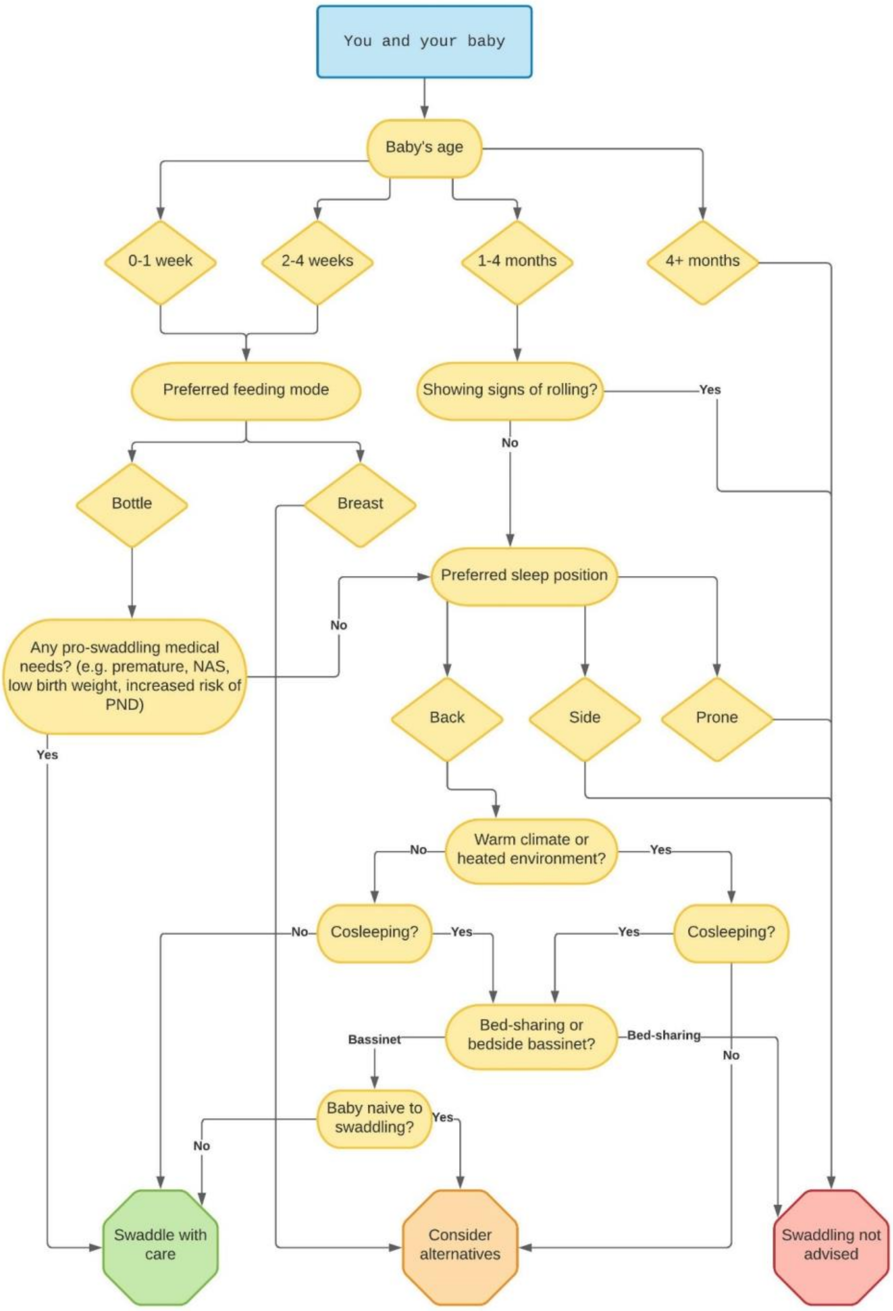
Recall that the introduction of scientific motherhood in the early 20th century was characterised by discord between maternal willingness to follow medical direction and their own proven abilities and instincts (Apple 1995). Numerous contemporary studies continue to show a disconnect between medical guidelines and maternal behaviours (Ball 2002, Ball 2003, Ball and Russell 2012, Ball and Russell 2012, Tully and Ball 2013, Volpe and Ball 2015, Tully, Stuebe et al. 2017, Ball 2020, Ball, Taylor et al. 2020) suggesting that practitioners are not discussing potential parenting trade-offs with their patients.

In response, anthropologists McKenna and Gettler 2017 called for "honest, bi-directional engagements" between parents and their health providers with regard to infant sleep practices (McKenna and Gettler 2017)(p4). Informed by such bioanthropological voices, recent UK guidance was amended to insist that health professionals discuss infant sleeping strategies with mothers; Acknowledging the role of parental-investment theory, specifically the trade-offs performed by each dyad, it was recommended that conversations include discussion of the likelihood of co-sleeping and to provide mothers with guidance on how to make their infant's sleep space as safe as possible (Unicef UK 2017, Blair, Ball et al. 2020). Mirroring the co-sleeping case, the findings of my survey (Chapter 9) suggest that health professionals are adopting an over-cautious approach when advising parents about swaddling, a conclusion previously reflected in the 'National Maternity Review' (NMR) (NHS England 2016).

My survey also found a statistically significant association between occupation type and opinion on a range of infant swaddle outcomes. This finding corroborated previous Australian and American surveys (Young, Gore et al. 2013, Yang, Ragen et al. 2018) and other qualitative studies (Lau and Hall 2016, McLeish, Harvey et al. 2019), and reflected concerns outlined in the NMR that "Many women expressed frustration over receiving conflicting advice from different healthcare professionals throughout their care" (p33). It has been argued that health care practitioners behave differently from each other largely because they do not have access to the best evidence, or they are unable to make an effective critique of the evidence (World Health Organization 1997). The sum of these sources clearly identifies the need for a detailed evidence-based approach to promote consistency in practice across infant care occupational roles. Such an approach must consider mothers' individual personal needs, along with their values, expectations, and beliefs about what is important because these factors will ultimately determine their caregiving decisions (Barry 2019).

A clinical guidance tree (CGT) could serve as a useful tool in addressing this communication deficit. A CGT is an enhanced form of decision tree for use in clinical practice. Unlike conventional medical decision trees, clinical guidance trees focus on use by non-specialists (Turner 2009). They are therefore ideal for facilitating maternal dialogue. This mother-centred approach recognises that a prohibitive ban on swaddling would be counter-productive (Ball 2017). In contrast, a CGT adopts the recommended 'risk minimization' approach. It enables users to explore choices at leisure and evaluate options that they may have otherwise not considered (Turner 2009). A preliminary CGT for swaddling is presented below.

Figure 59 Swaddling Clinical Guidance Tree (a prototype)



Current thinking maintains that health professionals should "seek solutions by listening to what matters to people and accepting the discomfort that may result" (Ham et al. 2018). Evidence shows that involving people in decisions about their care can lead to higher levels of satisfaction and improve treatment concordance (The Health Foundation, 2012, Coulter and Collins, 2011, as cited in Ham, Charles et al. 2018). Following this view, my proposed CGT has many benefits. It is based upon established guidelines pertaining to infant sleep and grades these using a traffic light system. Green advises swaddling in conjunction with safe sleep guidelines; Amber prompts mothers to reconsider alternative sleep interventions but does not prohibit swaddling; Red strongly advises against swaddling. Amber is the most dynamic of the three options, as it opens the door for discussion of trade-offs and contingency plans. When amber is selected, a form of motivational interviewing may be appropriate. Here, the health professional can guide the mother to clarify their strengths and aspirations, invoke their own motivations, weigh up options, and ultimately promote autonomy of decision making (Rollnick, Butler et al. 2010). The proposed CGT supports the WHO recommendation that guidelines are clearly focused on the “end user” (World Health Organization 1997)(p1) whilst also employing co-production through mutual discourse to improve overall patient care. The approach is respectful of maternal agency, facilitating a mother's right to choose how to care for her infant based on her own needs, circumstances, and purposes. Without this nuanced, inclusive and flexible approach, swaddling is likely to 'go underground' with parents concealing the practice from health professionals, as documented with bedsharing (Ball, Hooker et al. 1999, Ateah and Hamelin 2008, Ball 2017, McKenna and Gettler 2017).

The CGT is also context-specific and culturally respectful. It supports the notion that sleep environments can be made safe or unsafe based on specific maternal strategies (Volpe, Ball et al. 2013). It acknowledges that not all approaches to swaddling share the same risk factors, and that risks are cumulative in that swaddling is less safe for some dyads but not others (e.g., cosleeping dyads). This prototype CGT incorporates maternal trade-offs (e.g., preferred sleep position) alongside clinical trade-offs (e.g., medical need). It recognises that mothers and infants are individuals that develop at their own pace and have idiosyncratic sensitivities. Grounded in risk reduction principles rather than abstinence, it acknowledges that mothers may engage in sleep practices that are counter to guidelines (e.g., placing their infant prone to sleep) and filters these choices through the context of swaddling. In short, the CGT enables conversations that appreciate both the risks of swaddling and the benefits of swaddling in terms of *the dyad*.

Flowing vertically, the CGT begins by ascertaining infant age. The International Society for the Study and Prevention of Perinatal and Infant Death (ISPID) recommend it is safest to swaddle infants from birth (Horne 2020). In Section 2 I discussed the numerous factors increasing the risk of swaddling older infants. Although swaddling is generally safer for newborns, the mother’s preferred mode of feeding is an important consideration for this age group. The Lullaby Trust cite that breastfeeding behaviours and breast milk supply are established "typically at about one month of age" (The Lullaby Trust 2019)(p26). Until then, the risk of swaddling in undermining breastfeeding is significant via a range of mechanisms as outlined

Commented [BHL2]: And do you advise informing mothers about all the issues you previously raise associated with swaddling = infant stress, disassociation, rejection etc? i.e. do you increase the COST of swaddling by informing her of the potential negatives?

Commented [DAS3R2]: Those things are not ‘proven’ and not in clinical guidelines.

Commented [BHL4R2]: Is everything in clinical guidelines ‘proven’?

in the biobehavioural review (e.g., masking and reduction of feeding cues, minimising skin to skin, incorrect positioning). From a safety viewpoint, the AAP advises that mothers stop swaddling when their infant can roll (between 2 and 4 months old) (Kennedy and Glassy 2013). Each of these topics are included on the CGT so that mothers of newborn breastfed infants are advised to consider alternatives to swaddling (amber), and mothers of older infants demonstrating the agility to roll are advised against swaddling (red). Meanwhile, newborn bottle fed infants and those for whom swaddling would be medically therapeutic are advised to swaddle with care (green).

Next, on the topic of positioning, the proposed CGT addresses popular infant-care advice that suggests placing swaddled infants on their side or prone (Emmet 2018) by advising against this practice, in credence with well-established evidence (The Lullaby Trust 2019). The CGT then triggers dialogue concerning environmental temperature, providing practitioners with an opportunity to explain safe swaddle behaviours (e.g., dress infant in fewer layers, choose a lightweight blanket, ideal room temperature is between 16-20°C (The Lullaby Trust 2013, Task Force On Sudden Infant Death 2016). Next, the CGT considers the sleep environment in terms of co-sleeping. At this point, practitioners can explain that swaddling is not advised in conjunction with bed-sharing as infants need to be able move their arms and legs to make the co-sleeping adults aware of their presence and also need the ability to move covers from their faces (Lead, Lead et al. 2019). During this discussion, practitioners should precisely determine all available sleep environments including sofa-sharing and distinguish between bed-sharing and room-sharing. Here, an infant side-car bassinet (as described in Chapter 7--lab study) is a suggested alternative to bed-sharing. A bassinet may enable parents who wish to swaddle to do so in close proximity to their infant whilst adhering to safe sleep guidelines.

Lastly, naivety to swaddling is incorporated as an important deciding variable (The Lullaby Trust 2019). As discussed above, studies indicate that inadvertent adoption of infant-care interventions increases the risk of SIDS and is more dangerous than routine newborn adoption of those interventions (Sobralske and Gruber, 2009, as cited in Lau and Hall 2016), perhaps because pre-planned behaviours leave sufficient time to consider risk-reduction strategies. Yet, the progression of developmental stages over the first six months can trigger parents to re-examine sleep arrangements in an ad-hoc manner (Lau and Hall 2016). For instance, a switch from bed-sharing to cot sleeping may coincide with the introduction of swaddling as a transitionary aid (Stuebe and Tully 2019), or a peak in crying behaviour may trigger the introduction (Kommers, Truijens et al. 2017). Certainly, alleviation of infant crying is a predominant cross-cultural and cross-historical motivation for swaddling (Morris, James-Roberts et al. 2001, James-Roberts 2007, Blom, van Sleuwen et al. 2009, Vik, Grote et al. 2009). In normal infant developmental trajectory, the phenomena of end-of-the day fussiness and crying begins at around 3 weeks of age, peaking at about 8 weeks, and subsiding by 12 to 16 weeks of age (Brazelton 1962). Indeed, some paediatricians have recommended introducing the intervention at this point (Sparrow and Brazelton 2008) despite the ISPID urging against introducing swaddling at 3 months of age when SIDS risk is greatest (Horne 2020).

The theory of maternal deprivation and the potential for stress may be gently broached with parents on the green or amber pathway. The conversation should be tentative pending more research. Such research could inform guidelines which can then be incorporated into the CGT.

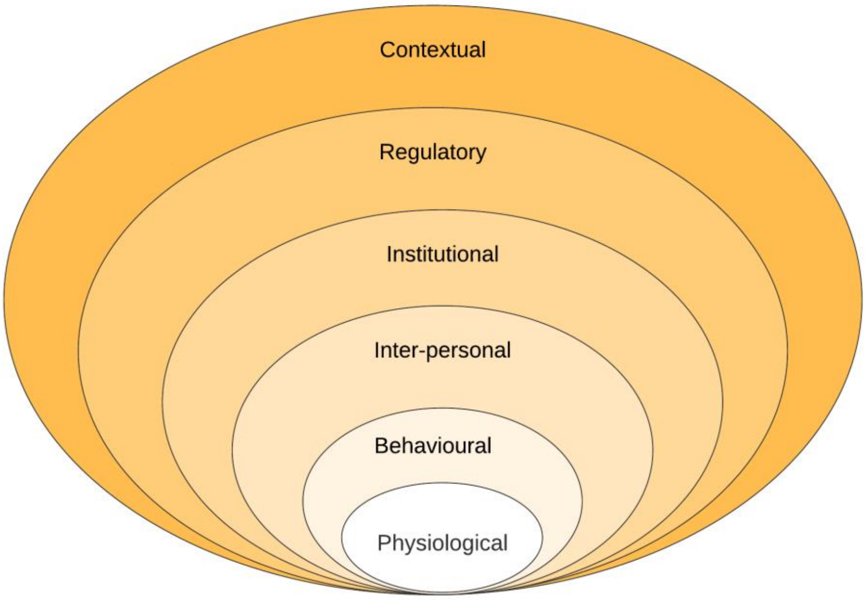
Summary

Scholars have emphasised the limits of perceiving health care as a product and instead advocate co-production based on trust and relationships (Batalden 2018). As clinical practice guidelines become more prominent as a key metric of quality healthcare, the need for conversational tools becomes all the more critical. To my knowledge my CGT is the first attempt to view swaddling through the lens of life history theory. The anthropological approach of incorporating evolutionary theory into clinical policy is growing in prominence, and is thought important in informing provision of more empathetic and effective clinical care (Stuebe and Tully 2020). Use of a CGT such as the one proposed provides a time-efficient and low-cost way for mothers and professionals to navigate the labyrinth of policy and guidelines. The tool may be used in support of the UNICEF 'Baby-Friendly Hospital Initiative' cited above. It can be amended as policies evolve and can be repurposed digitally for use on apps and websites. Research is needed to pilot and refine the CGT.

Section 6. Overall contribution to knowledge

I now turn from the theoretical and empirical to the methodological. Here, I will borrow from the notion of 'spheres of influence' to illustrate the sum of my thesis and its overall contribution to knowledge. Spheres of influence refers to the concept that individuals are enveloped within a number of domains, from the very personal micro-level (e.g., one's experience of one's body) to the broader macro-level (e.g., the socio-cultural context) (Kohno, Musa et al. 2016). I present a brief overview of how my thesis has identified and addressed knowledge gaps within each sphere of 'enquiry'.

Figure 60 Spheres of 'enquiry' (my own model).



6.1 Physiological

Beginning with the physiological domain, my biobehavioural review (Chapter 4) thoroughly explore the interplay between swaddling as an environmental intervention and infant physiological outcomes. Then, moving from secondary to primary data, my laboratory study (Chapter 7) investigated the impact of swaddling upon infant physiologic states (e.g., AS, QS) by triangulating biological markers such as oxygen saturation and heart rate with behavioural observation. Despite the historic nature of swaddling, knowledge of the physiological mechanisms involved in the intervention remained unclear at the time of research. My findings add to a very limited pool of data specifically concerning breastfed newborns naive to swaddling. These variables (breastfed and swaddle-naive) were previously distinguished in only one study (Richardson, Walker et al. 2010). My data support that study's findings, namely, that naive breastfed infants do not demonstrate alterations in sleep duration when swaddled. My contribution is unique however in that each infant in my study performed as their own control, and were also distinguished as 'exclusively' breastfed (i.e., never having consumed formula or other supplementation).

Another contribution to the physiological domain was my sensor innovation (Chapter 8). Swaddle tightness is likely an important modifying variable of physiologic state. For instance, the decreased arousability procured through swaddling is unlikely to be explained merely by the material's constant stimulation of the skin and thermal receptors, as Richardson and colleagues (Richardson, Walker et al. 2010) controlled for these factors and still found decreased arousability in swaddled infants. My sensor enables the important variable 'swaddle tightness' to be operationalised in future research, shedding further light on the interaction between pressure and infant physiology.

6.2 Behavioural

In the behavioural domain, my thesis interrogated both secondary data (biobehavioural review--Chapter 4) and primary data (lab study--Chapter 7). The latter built upon the biobehavioural review, utilising direct observation to identify infant behavioural parameters (e.g., rooting, crying, active awake). My chosen methodology is believed to be the most reliable and efficient approach for young infants (Grigg-Damberger, Gozal et al. 2007). Video recordings were made from three ceiling-mounted infra-red cameras which could be panned and zoomed remotely. This work, as applied behavioural research, was complimented by a systematic review of video methodologies (Chapter 6). The review contributed unique insights, as the only systematic review to critically assess video as a methodological technique in infant sleep enquiry.

6.3 Inter-personal

In the inter-personal domain, my lab work (Chapter 7) coded the communicative efforts of both infant and mother, and discussed these data with regard to the interplay between parties. This contribution is unique, being the first study to explore the impact of swaddling upon maternal-infant sleep interaction and sleep orientation.

Further in the inter-personal domain, I performed extensive literature reviews (Chapters 2-5) with a focus on the mother-infant dyad that rejected the conventional mother/infant dichotomy. This subtle shift from the individualistic (intra-personal) to the collective (inter-personal) enabled swaddling to be interrogated through the lens of the dyad, which anthropologists maintain is the ideal unit for study and analysis (McKenna 2004).

6.4 Institutional

In the institutional domain, my clinical review (Chapter 5) explored how swaddling is negotiated within the health care system. This secondary data was again complemented by primary data collection and analysis using survey (Chapter 9). My work sought to ascertain the swaddling-related knowledge and opinions of health professionals based in UK 'anchor institutions', namely large, public sector organisations whose long-term sustainability is tied to the wellbeing of the populations they serve (The Health Foundation 2021). Through my survey I was able to investigate whether swaddling opinion differed according to occupation type and occupation length. My data are unique, as the first UK-based swaddling survey of health professionals.

6.5 Regulatory

The results of my survey (Chapter 9) were filtered through a regulatory lens. I examined the professionals' respective adherence and deviance from established swaddling guidelines. I also drew upon previous foreign surveys to compare and contrast regulatory adherence internationally.

6.6 Contextual

Finally, in the wider contextual domain, I used secondary data to perform a thorough socio-historical interrogation of swaddling (Chapter 3). Here I was able to highlight historical changes and intercultural variations, considering diversity amongst both nationalities and distinct cultural groups. I have also looked at deep history by conducting an evolutionary review of the swaddling debate (Chapter 2). Using the context of our ancestral environments, I offered insights into the intersection between beneficial and detrimental maternal-infant behaviours pertaining to swaddling.

Section 7. Limitations and reflections

> "*Between reality and its representation is a process of knowledge construction which is cultural, partial, complex and positioned within a social and historical context*." (Davis, 2018, as cited in Davis 2021)(p11).

At this juncture I identify common limitations across the sum of projects. This high-level approach will attempt to combine common factors inherent in the thesis as a coherent whole. After this discussion, I 'turn the researcher lens back onto myself' by taking a reflective look at my personal context and speculate its potential impact on the thesis (Dodgson 2019).

7.1 Sampling

All projects relied upon online means of recruitment. This may have led to the under-representation or over-representation of particular groups within each respective sample. I am unable to ascertain why some participants chose to take part in the studies, whilst others did not.

Further, as with any small study, the outcomes observed in my projects cannot be assumed to imply predictive value. By adopting quasi-experimental (lab project), evaluative (sensor project), and exploratory (survey project) research designs, I cannot ascertain causal relationships between variables, but only associations or trends.

7.2 Methodologies

In the systematic review I suggested that ideas and theories generated in the field of infant sleep research are directly related to the research methodologies. Preceding the present thesis, I performed a masters-level enquiry into swaddling, including both field research and a systematic review. The sum of this work posed the basis for the present work. Identifying the methodological, theoretical and epistemological tensions and problems at preconceptual stage, enabled a more robust research design and heightened confidence than would perhaps otherwise been the case had my previous research focused on a different topic. To quote Boote and Beile (Brown, Klingaman et al. 2005), "less-successful researchers have perhaps never learned to develop productive research questions because they have superficial understanding of the problems of their field" (Boote and Beile 2005)(p11).

Further, conducting a methodological systematic review as a component of the overall thesis provided me with the opportunity to explore a wide variety of methodologies and to master the critical analytical skill of comparing methodologies. I was able to use the results of the review to critically reflect upon my own methodological choices.

I chose a broadly multi or mixed-methods approach to my thesis, with a view to achieving a multi-dimensional exploration of my complex topic. I applied mixed-methods in distinctive ways depending on the nature of the hypotheses at hand. For instance, in both the lab and survey projects I used mixed-methods in a 'nesting' fashion. This term refers to the extent to which multiple data types are collected from the same participants (Small 2011). The strength of nesting lies in the presence of multiple data points per subject, which allow different methods to "penetrate deeper into individual units" (p69).

From a slightly different epistemological view, my lab project is distinct in that it adopted a "transformative mixed methods research design" (Driscoll, Appiah-Yeboah et al. 2007)(p20). Here, I transformed data from qualitative video observations into quantitative frequencies. This transformative process has been termed 'quantitizing' (Tashakkori and Teddlie, 1998, as cited in Driscoll, Appiah-Yeboah et al. 2007). Other scholars have used a different notion to contextualise this process, that of a qualitative-quantitative research continuum underscoring what they perceive to be the ‘false dichotomy’ of methodological discourse (Walsh 2012). As behavioural in nature, my lab data consisted of qualitative and quantitative constructs. I found the process of transforming one data type to another to be complex and time consuming with a steep 'learning curve' and emerging limitations. By quantifying the video observations ethologically, I lost considerable depth and flexibility in subsequent analysis. In contrast to the fixed and one-dimensional nature of quantitized data, qualitative coding is multidimensional, meaning it provides insights into a host of interrelated conceptual themes (Driscoll, Appiah-Yeboah et al. 2007). Consequently I found some types of qualitative data challenging to transform. For instance, in fitting with my focus on the dyad as the major unit of analysis, it would be instructive to code mother-infant synchrony during swaddled versus unswaddled conditions. However, the coding software programme did not offer the functionality to link behaviours between participants. Rather, such enquiry would require going through all the data by hand and noting the form and frequency of synchronous exchanges, or learning a new type of behavioural coding software from scratch. The resources required to achieve this were beyond my thesis timeframe.

As with biobehavioural phenomena (e.g. dyadic synchrony), social metrics can also defy dichotomous categorization. Indeed, when I explored health professionals' perceptions, attitudes and beliefs in my survey project, similar methodological tensions surfaced. In contrast to the transformative design of the lab project, my survey adopted a relatively simple design in which qualitative and quantitative data were collected concurrently. My aim was to obtain a deep understanding of topics by gathering qualitative data whilst assessing commonalities and patterns of responses by gathering quantitative data. In this respect, some scholars differentiate mixed methods study designs by the level of prioritization of one form of data over the other (Driscoll, Appiah-Yeboah et al. 2007). In my survey, I prioritised quantifiable multiple-choice question formats over free-text options, conducting considerably fewer of the latter. In hindsight, a more balanced approach between quantifiable and quantitative survey items would have been beneficial, as qualitative free-text responses can be used to validate or enhance quantitative responses. In other words, "the collection and analysis of embedded qualitative responses can augment and explain complex or contradictory survey responses" (Driscoll, Appiah-Yeboah et al. 2007)(p24). For example, in terms of routine versus non-routine swaddling, most respondents in my survey preferred non-routine swaddling, contrary to established guidelines. Exploring the topic solely in a dichotomous format (Routine swaddling/ Non-routine swaddling/ Not swaddling at all) precluded my ability to explore the reasons *why* the respondents preferred non-routine swaddling - a critical policy objective. Future research could explore this disparity by performing in-depth interviews, and the resulting themes could be quantified and integrated with my survey findings.

In a similarly limiting sense, by determining conceptual categories *prior* to data collection, all of my studies were reductive. This meant that I could not change conceptual categories in response to new insights in analysis. As a result of time constraints, I could not reconfigure my coding scheme in the midst of the research process, especially once I had begun statistical analyses with the existing dataset.

In many instances the research questions and hypotheses dictated the design of the study. For example, the sensor and systematic review projects required uni-dimensional single method approaches rather than mixed-methods. Clearly for the sensor, the research question was succinctly defined. The key variable of interest 'pressure' was quantifiable by nature and therefore the project necessitated a quantitative analytical framework. For the systematic review, the research questions were explorative in nature, meaning that a quantitative/meta-analysis design would have been inappropriate. In this instance, the need to collect and analyse iterative data from each study necessitated a qualitative/narrative approach. Regrettably, the laborious nature of this process forced a limitation on the number of databases I could feasibly search. This is one of the reasons why systematic reviews are typically conducted by teams of researchers (Uttley and Montgomery 2017, Lasserson, Thomas et al. 2019). Indeed, time and capacity constraints are often exaggerated in this field of research (Bhavsar and Waddington, 2015, as cited in Baloyi 2016).

7.3 Reflexivity

Reflexivity refers to the examination of one's own beliefs, judgments and practices during the research process and how these may have influenced the research (Jootun, McGhee et al. 2009). In this section I use reflexivity, not to legitimise my personal philosophy, but to embed my research within an epistemological context.

To begin with the general socio-context of the research; As Bourdieu's (2017) theory of 'habitus' implies, some of my ideas, expressions and choices may have been shaped by my lifetime exposure to a western frame of reference, and specifically my working class background. From a subjective perspective, my Western cultural heritage biases me towards individualist rather than collectivist thinking, and my working-class upbringing influences my perceptions of resource scarcity and constraint. Together, these socioeconomic cognitions may have shaped my methodological decisions, for instance, influencing how I related to participants, and how I delegated resources. Further overarching these factors was the political and economic climate, including the anxiety and uncertainty of both Brexit and the Covid-19 pandemic.

With regard to my analytical approach, my professional and academic background, including qualifying as a nursery nurse and obtaining a degree in early childhood studies, perhaps inclined me towards sympathy and advocacy of the very young, voiceless populous - infants. This in turn may have influenced my interpretation of the data and consequently the emergent theories crafted.

Regarding data analysis, my cognitive positioning is also epistemologically important. As an Autistic and broadly neurodiverse individual, I am innately drawn to positivist ways of constructing knowledge, i.e., the existence of an independent social reality, and the corresponding ability to discover objective truth (Small 2011). My neurological 'habitus' inclines me towards pattern finding, systemising, deeply immersing myself in each facet of the topic, and attending to fine details. More generally, Autism is linked to the ability to build a "detailed, sophisticated understanding" of a topic (Clouder, Karakus et al. 2020) and to "playful curiosity" and pattern seeking (Baron-Cohen 2020)(p17). These traits resulted in my making 'deep dives' into relevant topics, interrogating every aspect, then attempting to synthesise all of this data into novel explanations.[31] These core facets of my biobehavioural character undoubtedly influenced not only the design of my studies, but also my handling and processing of the data. This is clearly illustrated by my bias towards quantitative methods. Most of my thesis projects incorporated elements of quantitative enquiry, either wholly (lab project & sensor project) or in conjunction with qualitative elements (survey project).

The sleep lab as quasi-fieldwork

During my truth-seeking journey, I had the fortune to conduct research within the UK's only infant sleep laboratory. The responsibility of spearheading research within this unique and

[31] This may in part explain why my thesis is so long!

award-winning environment was both a privilege and a culture shock. The lab's facilities offered an intimate window into the biobehavioural lives of mothers and infants, within a relatively controlled environment. For the participants, my presence was felt like a researcher, asking questions, probing, observing and recording, however on the other hand, I was a mother, in kind with them. Thus, despite the artificial constraints of the lab environment, the data collection process personally felt very much like anthropological fieldwork in its purest sense. As an experienced breastfeeding mother, and author of a book on the topic, I considered myself privileged of an 'inside knowledge', and this allowed me to feel confident with the subject and with the participants. Empathic and positive interactions between researcher and participant are shown to increase retention rates in sleep research (Yu, Gumport et al. 2020). In my study, all dyads that participated on the first night of data collection, returned to complete the second night. Of course, against this intimate backdrop was the need to maintain empathic distance as a researcher, a challenge I found easier with emerging experience.

Regretfully, characteristics of lab participants (exclusively breastfed), the study design (two consecutive nights in the lab) and mode of recruitment (initially, the National Health Service) impacted recruitment success. Recruitment through the National Health Service was abandoned prematurely as a result of unforeseen circumstances (i.e., the lab facilities emigrated >20 miles). This resulted in the original health trust lacking suitability. To mitigate this problem, I used the lab's affiliation with the Baby Sleep Information Source, to serve as a backup recruitment stream for all projects.

The effortful data collection involved in sleep study is a well-known deterrent of participation (Yu, Gumport et al. 2020). From the outset, I had aimed to recruit around 30 dyads, as this would have given the project greater statistical power. Unfortunately, recruitment fell significantly short of this figure despite my best efforts, including for instance, identifying and liaising with local participant networks (e.g., community breastfeeding groups), and increasing gratuities. Indeed, the logistical challenges inherent in overnight monitoring have led most swaddling studies to focus on daytime 'naps' (Gerard, Harris et al. 2002, Richardson, Walker et al. 2009, Richardson, Walker et al. 2010). In contrast, my project required two overnight laboratory observations, and in an effort to minimise the impact of any within-infant developmental changes, each night was consecutive. Requiring participants to commit to consecutive nights without any 'recovery time' was a demanding endeavour, but not unique. Inadequate statistical power and recruitment bias are common in the field of sleep research (Gleason et al., 2014 as cited in)(Yu, Gumport et al. 2020). Overall, problems with recruitment disrupted the timetable for my research, and preoccupied my mental and physical resources more than initially anticipated. The logistics of having a young family myself compounded this challenge.

Conclusion

> *"Perhaps this dramatic array of conflicting findings is exactly what we need to see in one place, to appreciate just how compelling the demand is to create a new sub-field of infant-*

parent sleep research to be called Psycho-Anthro-Pediatrics" (McKenna and Gettler 2017)(p1).

In advocating for a new concerted field of infant sleep research, McKenna and Gettler (2017) opined the above. They were referring to the data on mother-infant bedsharing, but as this thesis has illuminated, the swaddling knowledgebase equally fits this description. Within the field of infant sleep research, very little information has been gathered about the effects of swaddling upon long-term maternal and infant well-being. For the purpose of health policy, this paucity of data should be compensated. Lack of knowledge as to infant physiology has produced deleterious outcomes through history to the present day (e.g., prone sleeping). Swaddling is no exception. The swaddling knowledgebase is confronted with several uncertainties due to gaps at the empirical level of which I have attempted to fill. Yet, at its very best, the knowledge constructed in this thesis is inherently partial.

The introductory quote to this chapter asks: *"Even if an infant has largely coped with an independence-promoting strategy, as a culture we have to ask ourselves, what have they learned?"* In reflection of my thesis, one might answer this question, as the author did, *"..Ultimately, they have learned that they are essentially alone"* (Miller and Commons 2014)(p128). By using lenses of social and biological medical anthropology, my thesis illuminates how poorly swaddling facilitates the human infant's unique biological and behavioural needs. Specifically, I propose that the stress response explains the deviant behavioural outcomes of swaddled infants. I have further proposed that introduction of swaddling to older infants may be especially deleterious, given the novelty of the intervention and disruption to routine. Upon swaddling, sleep associations established prior, such as self-soothing with the hands, become redundant and the infant experiences a sudden loss of mobility. Furthermore, I have generated the QS Rebound Hypothesis to illuminate the potential for swaddling to generate detrimental sleep outcomes. The hypothesis draws upon classical evolutionary understandings of sleep to suggest a link between habituation, sleep state and the introduction of a novel stimulus.

My contributions to the field, albeit limited, challenge the belief that swaddling as a behavioural intervention, particular for sleep, improves outcomes for mothers and infants. My work highlights how such beliefs are historically constructed, overlook feeding problems, and bias interpretation of data. My findings specifically urge for holistic recommendations that are mindful of the risks of introducing swaddling to older infants whilst also acknowledging the possible impacts of neonatal swaddling upon establishment of breastfeeding. In sum, when framed through an anthropological lens, the intervention of swaddling can only disrupt normal infant and maternal behaviour, with potential ill-effects on the health and wellbeing of infants that we ignore at our peril.

Chapter 11. Conclusion

"How little the single scientist knows in relation to the total community of inquirers.." (Kalleberg, 2007, as cited in Davis 2021)(p141).

In the previous chapter I commended Mileva-Seitz's suggestion of a new concerted field of infant sleep research, Psycho-Anthro-Pediatrics (Mileva-Seitz, Bakermans-Kranenburg et al. 2017). The scholars called for a more systematic and comprehensive evidence base, that moves beyond dichotomous (yes/no) generalizations and towards "more 'broad-based', eclectic research designs [that may] better explain and appreciate outcome variability" (McKenna and Gettler 2017)(p1). In this closing chapter I aim to solidify my work's position within this emerging field. First, I will briefly outline the focus of my overall argument. Next, I will discuss the significance, meaning and value of my argument to various stakeholders in the field. Finally, I demonstrate what my research may mean within the context of Psycho-Anthro-Pediatrics and the ways in which my work speaks back to the existing body of research. During that discussion I will suggest a paradigm shift.

The Argument

The thesis was inspired by McKenna's hypothesis that solitary sleeping removes the infant from the regulatory effects of its mother's body and places it in a more physiologically challenging sleep environment (McKenna 1996). My work built upon this hypothesis by likening the dynamics of solitary sleeping with those procured through swaddling. When viewed through this lens, swaddling was revealed as exacerbating the limited biological and behavioural competence of the immature infant. I argued that swaddling produces deviations in sleep ecology, the ultimate result of which, I theorised as the biobehavioural decoupling of mother and infant.

My thesis has echoed the voices of numerous scholars, particularly those situated within the field of sociocultural anthropology. I argued that, not only does swaddle implementation (habitual versus non-routine, tight versus loose) appear to have important implications for infant physiology, application is influenced by social factors that promote variation from parent to parent. Such factors include parental conceptions of infancy, for instance, whether infants ought to be dependent or independent. I further maintained that the sensory manipulation of swaddling (mimicking inter-uterine conditions) is mismatched to the evolutionary expectation that newborn infants' function in the specific sensory environment of their mother's arms (McKenna 2016). In doing so, I underscored the biobehavioural nature of the maternal body as regulatory and responsive, positioning swaddling as undermining this postnatal effectiveness. Relatedly, I argued that swaddling is experienced by infants as a form of abandonment or maternal deprivation. A consequence of this dynamic, I contended, is the triggering of a stress response. I highlighted the behaviour of swaddled infants (as catalogued in numerous studies (as catalogued in numerous studies; e.g., Franco, Seret et al. 2004, Ohgi, Akiyama et al. 2004, van Sleuwen, L'Hoir M et al. 2006, Caiola 2007, van Sleuwen, Engelberts et al. 2007) mirrors the behaviours of stressed infants, namely a 'shutdown' response, characterised by 'avoidance' or 'freezing'.

The Findings

This thesis has combined the strengths of quantitative and qualitative methodology through primary and secondary data, in an effort to compensate for the limitations of each. Through a holistic, psycho-anthro-pediatric approach, the thesis performed a thorough anthropological interrogation of swaddling, with nods to numerous additional disciplines. My work unveiled a range of ethical, methodological, and ontological tensions, and highlighted gaps in knowledge. Firstly, the literature review positioned swaddling as a universal practice implemented in culturally specific ways. It revealed that infant needs and parental responses are dynamic and interdependent. The embodiment of infants and their interembodiment with their mothers were found to be performed through the dichotomy of proximal and distal care. Next, the systematic review provided in-depth evidence highlighting video as a significant resource for infant sleep researchers. Specific methodological 'trade-offs' in validity were identified, suggesting that positivist and scientific ontologies dominate the field of infant sleep research. This work set the scene for the subsequent lab project, which applied video capture as the dominant methodology. The findings of that project indicated that naïve breastfed infants' respond to swaddling in a way that deviates from that previously seen in formula fed subjects. Namely, the naïve breastfed infants did not demonstrate alterations in sleep length when swaddled, but experienced an extension of active sleep. To address a limitation in that study (and in the field in general), the subsequent sensor project showcased a successful novel method of calibrating swaddle tightness. The results indicated a high degree of reliability under experimental conditions. Finally, the survey project indicated a high level of professional knowledge pertaining to UK safe sleep infant-care recommendations. Newborns were thought most appropriate for swaddling, with significant preference given towards non-routine swaddling and the 'hands out' configuration.

The Importance

> *"Infant sleep development in different micro- and macroenvironments is an important emerging research area, where the development of robust methodologies is needed to facilitate cross-cultural study" (Ball, Tomori et al. 2019)(p599).*

Inspired by anthropological critiques of clinical and populist conceptualisations of infant sleep (as summarised in Ball, Tomori et al. 2019), this thesis has broached new possibilities in terms of theory and method that can be tested cross-culturally. I have created several novel hypotheses, introduced pressure sensing to measure swaddle tightness, and fashioned standardised tools for research reporting (video methodology template) and clinical practice (Clinical Guidance Tool). "Improving study designs" is cited as a primary goal of the psycho-anthro-pediatric framework (Mileva-Seitz, Bakermans-Kranenburg et al. 2017)(p16).

In contributing to the literatures regarding the interplay between swaddling and sleep state outcomes, I have responded to calls from two systematic reviews (van Sleuwen, Engelberts et al. 2007, Dixley 2015). In doing so, my work has built upon our understanding of external influences as regulators of infant sleep. My QS rebound hypothesis contributes to the field by elaborating on the theorised role of active sleep as a driver of habituation (Roffwarg, Muzio et al. 1966, Pearlman 1979, Denenberg and Thoman 1981, McNamara, Wulbrand et al. 1997, Wulbrand, McNamara et al. 1998, Mirmiran and Ariagno 2003, Franklin and Zyphur 2005, Graven and Browne 2008). In doing so, it explains the outcome of swaddle studies in which time spent in AS significantly increased (Brackbill 1973, Gerard, Harris et al. 2002), including my own lab data involving swaddle-naïve infants.

With regard to stakeholders, my thesis may inform researchers working in a wide array of disciplines, and be of particular interest to health-care practitioners and policy makers. Specifically, my work could encourage interested persons to question whether swaddling optimizes the feeding, sleep, psychology and attachment of the dyad. For instance, to reiterate my concern from the previous chapter: If infants sleeping distally in rooms by themselves are at higher risk of SIDS than those sleeping proximal to a committed caregiver, could swaddling (and the distal caregiving style associated with it) predispose infants to the same fate? At the very least, a reliance on distal infant care could have profoundly deleterious consequences for breastfeeding, given the interrelationship of bodily proximity and suckling (Ball, Tomori et al. 2019), and this should be acknowledged and investigated. Most health visitors in my survey (Chapter 9) did not believe swaddling impacted breastfeeding, and so my work could provoke new scope for training that draws attention to new variables. In this vein, my thesis also highlighted the view of health professionals that swaddling should only be practiced non-routinely (survey--Chapter 9). This could further provoke a modification of current training, given that non-routinely swaddled infants have been shown to demonstrate higher arousal thresholds (Gerard, Harris et al. 2002) considered a risk factor for SIDS (Harper and Kinney 2010). Indeed, my work would be of benefit to the continuing professional development of all health professionals. At the very least, in practical terms, researchers, policy makers and health professionals will no longer be limited to describing swaddle tightness in subjective terms. The advent of my calibration sensor could have significant implications for these stakeholders.

The Implications

As lamented for decades by numerous anthropologists (e.g., McKenna 1986, McKenna, Thoman et al. 1993, Mosko, McKenna et al. 1993, Trevathan and McKenna 1994, Jones and Ball 2012, Tomori 2014, McKenna and Gettler 2016) and reflected in my systematic review, the bulk of infant sleep literatures are biomedical and echo the Western paediatric infant sleep paradigm. The swaddling literatures are no exception. Swaddling is conceptualised as a potential form of pedagogy, 'like a drug', framed through the medicalised language of efficacy. The field is dominated by the question of whether, and to what extent, swaddling facilitates the - predominantly Western - ideal of a docile infant. Methodology and epistemology are conducted against a backdrop in which isolation is the 'normal' setting for infant sleep, and continuous sleep the desirable outcome. Under this framework, the mental well-being of many parents is irretrievably linked to the degree to which their infant adheres to that ideal (Symon and Crichton 2017, Whittall, Kahn et al. 2021). Accordingly, most swaddle studies use total sleep time, number of night wakings, or sleep efficiency as outcome measures, rather than feeding, mother-infant interaction, or long-term outcomes like attachment, cognitive or social development. The biomedical paradigm also frames the formula- or bottle-fed infant as the default subject. In swaddle studies, very few even declared feeding mode and fewer still involved breastfed infants. These factors have cultivated specific types of research question at the expense of other, arguably more pressing, questions. Through this lens, 'good' infant sleep is characterized as independent sleep onset, longer consolidated sleep periods, less signalling, and more sleep per sleep–wake cycle (Schwichtenberg et al, 2013, as cited in Barry 2020)(p17). Conversely, 'bad' infant sleep is regarded as issues with sleep latency, short duration of sleep, nighttime crying and frequent nighttime awakenings (Blunden, Thompson et al. 2011, De Beritto 2020). Data resulting from this conversation associate swaddling with more 'good' than 'bad' infant sleep. However, I question the utility of knowledge that stems from a systemic blindness to the interrelated and interembodied nature of the dyad. Nonetheless, this dominant paradigm of Western medical authoritative knowledge continues to successfully control institutional and public discourse (McKenna 2016).

Conversely, my thesis has provided a springboard for inter-subfield and interdisciplinary conversations of a different character. I argue we need to move from a narrative of efficacy to a narrative of risk-benefit; from a focus upon swaddling's effectiveness, towards examining the potential risks/benefits (to the dyad). This paradigm shift would necessitate a fundamental change in basic concepts and experimental practices. I agree with those scholars asserting the behaviour of unswaddled, breastsleeping infants should always inform the baseline for infant sleep (e.g., McKenna 1986, McKenna, Thoman et al. 1993, Mosko, McKenna et al. 1993, Trevathan and McKenna 1994, Jones and

Ball 2012, Tomori 2014, Bonamy 2016, McKenna and Gettler 2016). Numerous infant care interventions, not least swaddling, should be assessed against this benchmark. Future research can explore how adaptive infants are to sleep ecologies like swaddling that so obviously stray from the evolutionary norm. Outcomes of such research may support my own findings and the findings of previous anthropologists, highlighting the interrelationship of bodily proximity and breastfeeding (Ball, Tomori et al. 2019) – i.e. the species-specific evolutionary norm. As mentioned in the previous chapter, this paradigm shift is not intended to undermine the critical importance and role of maternal agency, but to facilitate that agency by engineering ways in which swaddling can be made safer, thus strengthening mother-infant wellbeing.

By investigating infants naive to swaddling (also the evolutionary norm), my sleep lab project (Chapter 7) added to the sparse knowledgebase around habituation. My findings corroborated the only previous study to explore naive infants (Richardson, Walker et al. 2010). The results raise the question, if swaddling acts like a drug, are the results 'dose-specific'? Certainly, the risks of swaddling, and indeed, the benefits, cannot be investigated if researchers do not ask the question because they assume the benefits outweigh the risks. Once we transfer focus to conducting risk-benefit appraisals, public bodies such as The American Academy of Paediatrics, UNICEF, and the NHS, can fruitfully and purposively scope an official stance on the intervention. As with bedsharing, the heterogeneous nature of swaddling and the varied ways in which it is applied, make it appropriate for assessment upon a benefits-to-risks continuum (McKenna and Gettler 2017). Following this approach, eventual guidelines can procure more holistic, appropriate, and sustainable health outcomes. Resources such as my Clinical Guidance Tool can then be modified and used to navigate the multiplicity of identifiable interacting (modifiable) factors of risk-benefit with a view to mitigating adverse outcomes.

My proposed paradigm shift opens up a new research agenda. For instance, my QS rebound hypothesis could undergo empirical testing, or my stress hypotheses could be explored through hormone study, further highlighting infant hormonal development as impacted by night-time-care behaviour (Joseph et al, 2015, as cited in Ball, Tomori et al. 2019). Such research may provoke a revisitation of previous literature causing scholars to see catalogued infant behaviour in an entirely different way. Certainly, future research should not simply share anthropological insights with other fields, but actively *co-create* it. I hope the theoretical and methodological approach adopted in this thesis has demonstrated, however tentatively, how such work may look.

Final word

As an integrated anthropology of swaddling, this thesis slots into the progressive field of Psycho-Anthro-Pediatrics. My work has systemized not only the evidence around swaddling, but also the theoretical underpinnings and the methodologies used in the field. The ultimate aim was to enhance understanding of the infant and maternal-level consequences of swaddling through an evidence-based evaluation. In the footsteps of previous Psycho-Anthro-Pediatric scholars, my work has highlighted tension between the Western paediatric paradigm and maternal–infant evolved biology. It has revealed a paediatric preoccupation with swaddling's effectiveness as a sleep induction tool, indeed 'a drug', that has overshadowed the fundamental issue of its desirability. As with any intervention, caregivers need to know the potential risks of swaddling, otherwise a decision to swaddle is not an informed one. I have suggested a paradigm shift through which researchers can interrogate and ultimately de-centre the dominant biomedical assumption of swaddling as a relatively mundane implement. Such a paradigm switch is the first step towards producing public health recommendations that are sufficiently elastic to be pragmatically useful, and may even lead us to question whether ‘switching off the baby’ is ethically defensible, morally defensible, or even necessary.

Appendix 1. Systematic review, study extraction template

Data to be extracted	*Notes*
BASIC DESCRIPTIVE INFORMATION	
Title of study	
Author	
Year of publication	
Study objective as stated by authors	
Length of video recording	
Other methodologies used	
Research setting	
Data analysis (time/event sampling)	
Discipline	
Synopsis	
SPIDER	
Sample	
Phenomenon of Interest (what was measured?)	
Design (how was it measured?)	
Evaluation (outcomes)	
Research type (qual/quant/mixed)	
DETAILED METHODOLOGICAL INFORMATION	

Theoretical position (inductive/deductive/narrative-evolving)	
Number and type of cameras used	
Positioning of recording equipment	
Who is operating the camera/s? (e.g., researcher in separate room)	
Any technical effect (e.g. limitations of camera lens producing a truncated view)	
Type of outcome observed (i.e. continuous such as sleep, or binary "events" such as vocalisations, awakenings).	
Mode of data management	
Editing of data	
Use of pre-established coding scheme or codes derived from the data?	
Coding software used	
Is coding microanalytic or macroanalytic	
Analytic plan	
Explanation of findings	
Ethical considerations	

Appendix 2. Systematic review, Mixed Methods Appraisal Tool (MMAT)

Mixed Methods Appraisal Tool (MMAT), version 2018

Category of study designs	Methodological quality criteria	Responses			
		Yes	No	Can't tell	Comments
Screening questions (for all types)	S1. Are there clear research questions?				
	S2. Do the collected data allow to address the research questions?				
	Further appraisal may not be feasible or appropriate when the answer is 'No' or 'Can't tell' to one or both screening questions.				
1. Qualitative	1.1. Is the qualitative approach appropriate to answer the research question?				
	1.2. Are the qualitative data collection methods adequate to address the research question?				
	1.3. Are the findings adequately derived from the data?				
	1.4. Is the interpretation of results sufficiently substantiated by data?				
	1.5. Is there coherence between qualitative data sources, collection, analysis and interpretation?				
2. Quantitative randomized controlled trials	2.1. Is randomization appropriately performed?				
	2.2. Are the groups comparable at baseline?				
	2.3. Are there complete outcome data?				
	2.4. Are outcome assessors blinded to the intervention provided?				
	2.5 Did the participants adhere to the assigned intervention?				
3. Quantitative non-randomized	3.1. Are the participants representative of the target population?				
	3.2. Are measurements appropriate regarding both the outcome and intervention (or exposure)?				
	3.3. Are there complete outcome data?				
	3.4. Are the confounders accounted for in the design and analysis?				
	3.5. During the study period, is the intervention administered (or exposure occurred) as intended?				
4. Quantitative descriptive	4.1. Is the sampling strategy relevant to address the research question?				
	4.2. Is the sample representative of the target population?				
	4.3. Are the measurements appropriate?				
	4.4. Is the risk of nonresponse bias low?				
	4.5. Is the statistical analysis appropriate to answer the research question?				
5. Mixed methods	5.1. Is there an adequate rationale for using a mixed methods design to address the research question?				
	5.2. Are the different components of the study effectively integrated to answer the research question?				
	5.3. Are the outputs of the integration of qualitative and quantitative components adequately interpreted?				
	5.4. Are divergences and inconsistencies between quantitative and qualitative results adequately addressed?				
	5.5. Do the different components of the study adhere to the quality criteria of each tradition of the methods involved?				

Source: (Hong, Pluye et al. 2018)

Appendix 3. Lab study, online 'registration of interest' form

Swaddle

Sleep Study

Durham

University

Swaddle Sleep Study Registration of Interest

Page I

Welcome

By providing your details on this form you are letting us know that you are willing to consider taking part in the Swaddle Sleep Study, and are interested in receiving more information. You are not committing yourself to taking part yet. We will send you a participant information leaflet, and give you a chance to ask questions about what's involved. If you are willing to sign up we will ask you to complete a consent and enrolment form. You are welcome to visit the sleep lab and to meet us before you decide whether to take part.

Some of the questions below (e.g. baby's age, previous experience of swaddling etc) will be used to help us decide whether your baby meets the criteria needed to take part'.

Contact information

All contact information will be kept in a secure database during this study and will not be shared with anyone. This information will be destroyed when the study is over or if you decide you no longer want to take part in the study.

1. Full name Required

l.a. Address Required

l.b. Phone Required

Please enter a valid phone number.

l.c. Email Required

Please enter a valid email address.

I.d. Can we call on the phone number you have supplied? Required

Yes
No

2 / 6

Your availability

To participate in this study, we need you and your baby to spend a total of two nights in the lab, with dates as close together as possible. Sessions begin around 8pm and end around 8am.

I.e. Please list on which dates you could be available. Required

Page 2

Demographic Information

When we write our report from this study we will need to describe the group of people who took part, so we need to collect some information about you.

2. What is your baby's date of birth? Required

Dates need to be in the format 'DD/MM/YYYY', for example 27/03/2016.

(dd/mm/yyyy)

3. What is your own date of birth? Required

Dates need to be in the format 'DD/MM/YYYY', for example 27/03/1980.

(dd/mm/yyyy)

4. Do you smoke? Required

Yes

No

5. Do you regularly drink more than 14 units of alcohol per week (e.g. 6 glasses of wine) *Required

Yes

No

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6. Was your baby born prematurely? (before 37 weeks gestation). Required

Yes

No

7. Does your baby routinely use a dummy for night sleep? (i.e. more than once a week). *

Required

r No

8. Is your baby routinely swaddled? (i.e. more than once per week) Required

r No

9. Does your baby regularly sleep in bed with you? (i.e. more often than not)
Required

Yes
No

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Thank you for your time. We will be in touch soon.

Durham
University

Appendix 4. Lab study, enrolment form

Study ID:

STUDY ENROLMENT FORM for the Introducing Swaddling study

Lead researcher: Allison Dixley| allison.dixley@dur.ac.uk |07983714229

Please complete and return this form to the research team. All contact information will be kept in a secure database during this study and will not be shared with anyone. This information will be destroyed when the study is over or if you decide you no longer want to take part in the study.

CONTACT INFORMATION

Full name: ____

Address: ____

____

____

Phone (home): ____

Phone (mobile): ____

Email: ____

What is the best way for us to contact you?

- Post
- Phone call
- Email
- Text message
- Other: ____________________

Can we call either of the phone numbers you gave us? Yes No

ENROLMENT INFORMATION

What is your baby's date of birth? ______________________________

What is your own date of birth? ________________________________

Do you smoke? Yes No

Do you regularly drink more than 14 units of alcohol per week

(e.g. 6 glasses of wine) Yes No

Was your baby born prematurely? (before 37 weeks gestation). Yes No

Does your baby regularly use a dummy? Yes No

Has your baby ever been swaddled? Yes No

Would you like to receive a copy of the project results when it is finished? Yes No

If yes, this will be sent to the email address you have provided above.

Demographic Information

When we write our report from this study we will need to describe the group of people who took part, so we need to collect some information about you. Please circle an option or fill in the blank space below.

Marital status: Married / Living with partner / With partner, living apart / Single, no partner

Education: Up to age 16 / 16-18 / Vocational training / A levels / University / Post-graduate

Family Income: Below £10000 / Up to £20000 / Up to £30000 / Up to £40000 / Above £40k

Ethnicity (e.g. White British, British Pakistani, etc.):

____

Appendix 5. Lab study, information sheet

Calling all newborns!

Sleep lab research opportunity

Staff of the Durham University Parent-Baby Sleep Lab invite parents and babies to take part in a study looking at baby swaddling.

Who we are: The Parent-Infant Sleep Lab is the home for a group of researchers examining aspects of infant and child sleep and parent behaviour. We are interested in the effects swaddling has upon the wellbeing of babies' with special interest in their sleep and feeding behaviour.

Who do we need? You have been selected to receive this invitation as your NHS patient records show you are suitable for this research opportunity. We are looking for participants who are under 4 months old (and their mams!) who have never swaddled and who can participate in an overnight lab study. Swaddling is the wrapping of a baby so that arms and legs are restrained (see image above). If this technique is new to you, we'd love to have you take part!

What will it involve? If you agree to take part in this study you will be asked to sign a consent form that says you understand what the study is about and fill out a form giving us some basic details about you and your baby. You and your baby will spend two nights in the Sleep Lab. The Sleep Lab is equipped to be as comfortable and homely as possible: It has its own private bathroom, kitchenette, TV with integrated Freeview and DVD, sofa, a king-size bed and a cot.

Your baby will be observed in both swaddled and un-swaddled. Data will be collected via video recordings and devices which measure your baby's breathing and heart rate. This technology is safe and comfortable for your baby. The information we collect will be stored on a secure password-protected university device and analysed using software. Upon completion of the project, you will be given the opportunity to sign up for an email explaining the project findings. Any personal information will be anonymised for

A thank you: As a thank you gift for taking part in this study we will give you a £30 Love2Shop gift vouchers.

What are the benefits of taking part? You will be helping researchers to find out the effects that swaddling has on young babies. In particular, you will help us understand how swaddling influences babies' sleep, feeding and interaction. This knowledge will be used to inform health professionals, allowing them to advise parents more effectively.

What the potential risks of taking part? Although every effort has been made to keep the lab as safe and secure as possible, it is unclear how babies may respond to this novel environment and to a novel intervention (swaddling). In the event of an emergency, the research team has developed safety protocol.

What if I don't want to be in the study anymore? You do not have to take part in this study, but we hope you will choose to help us. You can change your mind at any point and if you decide that you do not wish to continue, just tell us you want to withdraw at any time; you do not have to give us a reason.

Confidentiality: Please note that all information we collect will be stored safely and will not be shared with anyone. We will give you a code so that your name will not be on any of the data forms and there will be no way of identifying you or your baby. In any reports we may write, information will be summarised so you cannot be identified. Approval from the NHS and Durham University Ethics Committee has been obtained and the project is covered by Durham University insurance.

What will happen to the results of this study? The results of this study will be collected and analysed, so we can publish them. You and your baby's identities will be confidential. You may ask for a copy of these reports.

Who is organising and funding this study? This study has been organised by staff of the Durham University Parent-Infant Sleep Lab and is funded by Durham University.

What to expect during the consent process: After you have read this sheet, please email the lead researcher with any questions and to receive a consent form: Allison.dixley@durham.ac.uk

Disclaimer: Durham University holds Public Liability ("negligent harm") and Clinical Trial ("non-negligent harm") insurance policies, which apply to this study. If you can demonstrate that you experienced harm or injury as a result of your participation in this trial, you will be eligible to claim compensation without having to prove that Durham University is at fault. If the harm resulted from any procedure, which is not part of the study, Durham University will not be required to compensate you in this way. Your legal rights to claim compensation for injury where you can prove negligence are not affected.

Thank you for reading this information sheet and considering taking part in this study.

Appendix 6. Lab study, consent form

CONSENT FORM

Title of Project: The Swaddle Sleep Study

Project Director: Allison Dixley

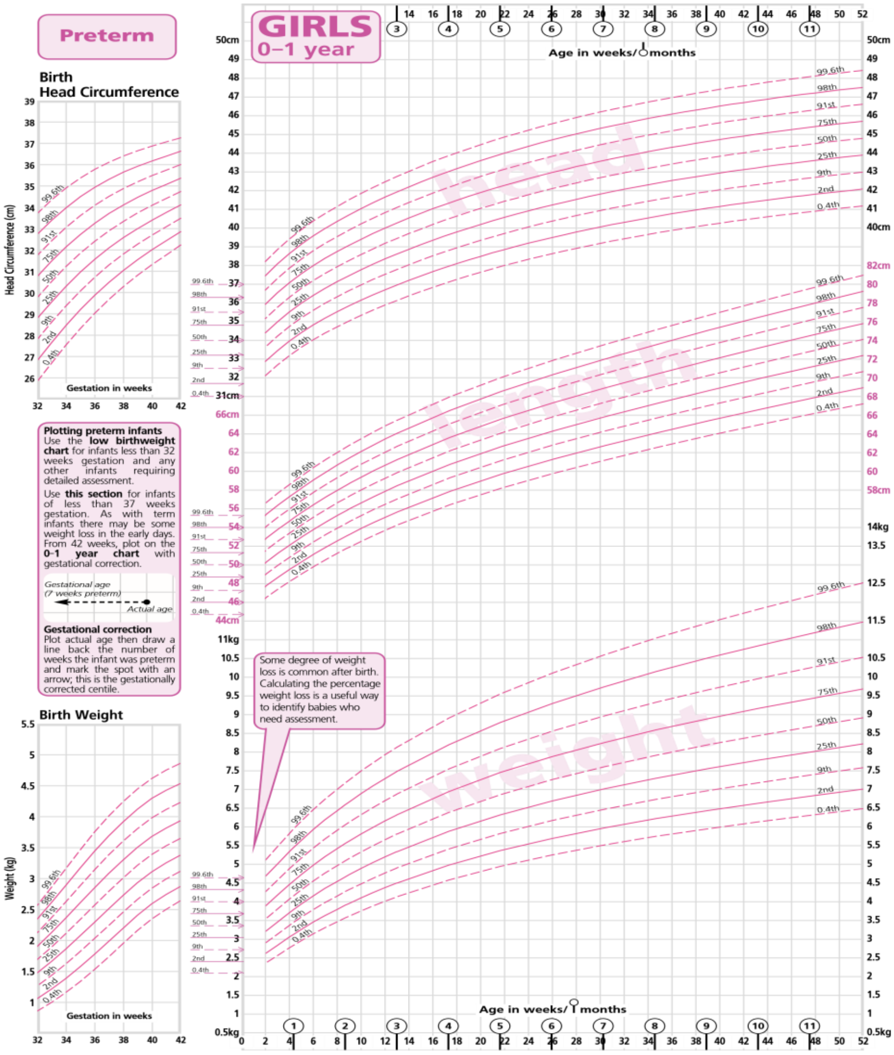
Please initial box

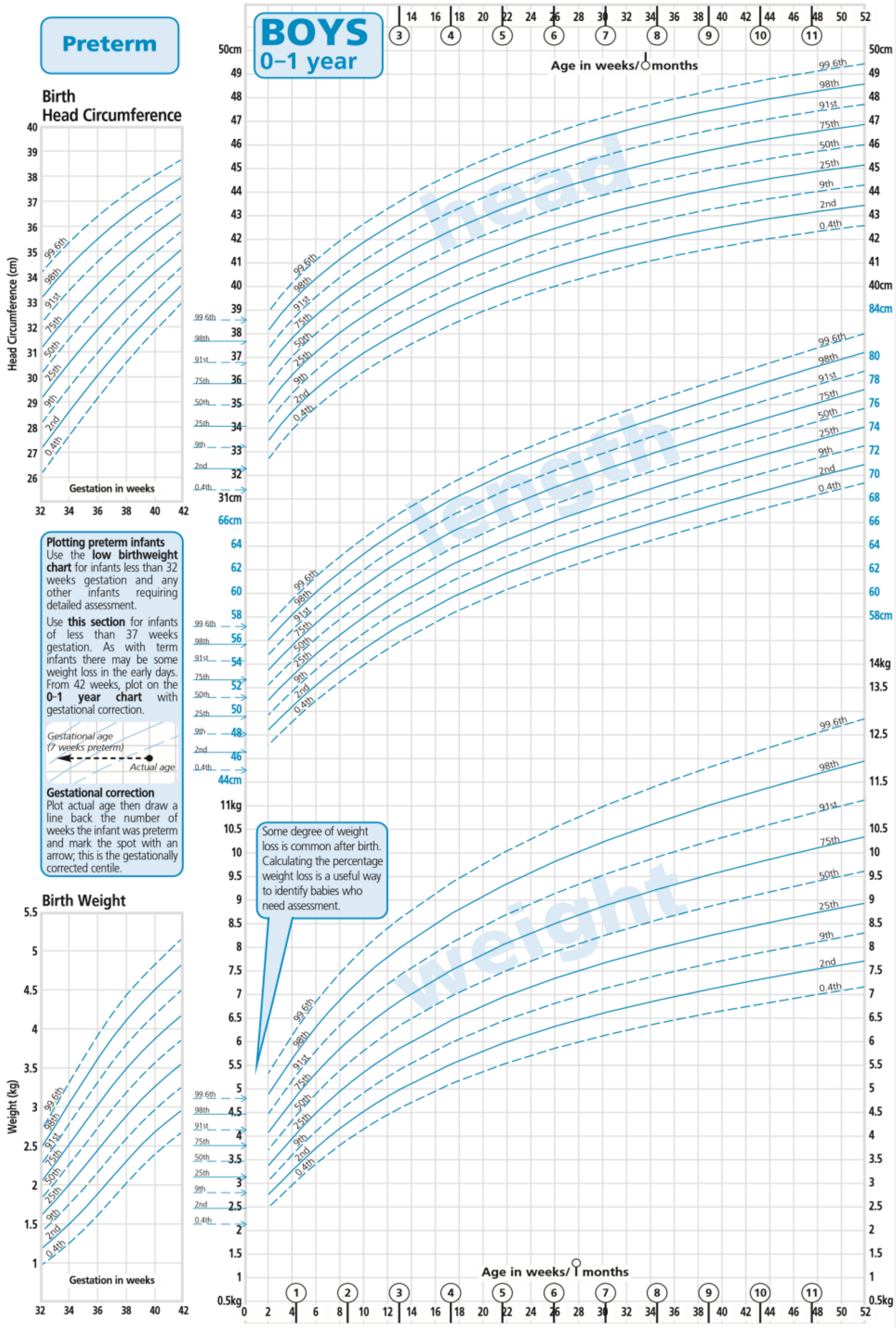
1. I confirm that I have read the information sheet dated...........................for this study and had the chance to consider the information. ☐
2. I have had the chance to ask questions and have had these answered by .... (a member of the research staff). ☐
3. I understand that my participation is voluntary and that I am free to withdraw at any time without giving any reason, without my medical care or legal rights being affected. ☐
4. I understand that the information collected about me will be used to support other research in the future, and may be summarized and shared anonymously with other researchers. ☐
5. I understand that a copy of this consent form will be kept in the Site File. ☐
6. I am willing for myself and my baby to be video-recorded as part of this study. ☐
7. I permit still-photographs from video recordings to be used in future publications and conference presentations if identifying features in such photographs are blurred. ☐
8. I am willing to take part and for my baby to take part in this study. ☐

______________________	______________________	______________________
Name of Participant	Date	Signature

Name of Person taking consent	Date	Signature

Appendix 7. Sensor study, World Health Organisation Child Growth Standards




Preterm
BOYS
0–1 year
Birth
Head Circumference
Head Circumference (cm)
Gestation in weeks
Age in weeks/months
head
length
weight
Plotting preterm infants
Use the **low birthweight chart** for infants less than 32 weeks gestation and any other infants requiring detailed assessment.
Use **this section** for infants of less than 37 weeks gestation. As with term infants there may be some weight loss in the early days. From 42 weeks, plot on the **0-1 year chart** with gestational correction.
Gestational age (7 weeks preterm)
Actual age
Gestational correction
Plot actual age then draw a line back the number of weeks the infant was preterm and mark the spot with an arrow; this is the gestationally corrected centile.
Some degree of weight loss is common after birth. Calculating the percentage weight loss is a useful way to identify babies who need assessment.
Birth Weight
Weight (kg)
99.6th
98th
91st
75th
50th
25th
9th
2nd
0.4th

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