Sedentary time during pregnancy and gestational diabetes risk: a mixed methods approach among women in the UK

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Abstract

Introduction: Sedentary time is associated with increased risk of type 2 diabetes, but the association between sedentary time and gestational diabetes (GDM) has not been tested. The primary aim of this mixed-methods study was to test associations between objectively measured sedentary time during pregnancy, as well as time spent in two specific sedentary behaviours (television time and occupational sitting time), and incident GDM, glucose levels, and other pregnancy-related outcomes. This thesis also aims to explore the social context of sedentary time during pregnancy.

Methods: Pregnant women (n=260) with a risk factor for gestational diabetes wore an activPAL accelerometer for one week at 20 weeks' gestation and reported their usual television time and occupational sitting time in the second trimester. Of these women, 192 provided 4 days of accelerometry data and were included in analyses. GDM diagnoses and glucose levels were measured through standard glucose tolerance tests at 24-28 weeks' gestation. Further outcomes were extracted from medical records following birth. Semi-structured interviews were conducted with a subsample (n=18) of participants in the third trimester.

Results: Objectively measured sedentary time was not associated with the development of GDM (OR 1.003 (95%CI 0.998, 1.008)), but was associated with fasting (β=0.16 (95%CI 0.01, 0.31)) and 2-hour glucose levels (β=0.15 (95%CI 0.01, 0.30)) among women who did not have GDM. Higher television time was associated with increased risk of GDM (OR 3.03 (95%CI 1.21, 7.96)), while higher occupational sitting was associated with decreased risk (OR 0.20 (95%CI 0.06, 0.59)). The main theme that emerged from the interviews was that there is a social expectation for women to sit down and to rest during their pregnancies.

Conclusion: Only television time was associated with increased likelihood of developing GDM. However, objectively measured sedentary time was associated with glucose levels during pregnancy. Any interventions designed to reduce sedentary time during pregnancy should aim to address broader social perceptions about the 'importance of rest' during pregnancy.

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Declaration and Statement of Copyright

I declare that the work presented in this thesis is my own. To the very best of my knowledge, it contains no material previously published or written by another person except where due acknowledgement has been made in the text.

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Preface

This thesis examines sedentary time during pregnancy among women in the UK who have a risk factor for gestational diabetes. The main aims of the study are to understand the prevalence, patterns, and predictors of objectively measured sedentary time and self-reported sedentary behaviours[1] such as television time and occupational sitting; to test the associations of sedentary time and sedentary behaviour with gestational diabetes risk and glucose levels; and to explore the ways in which the social context of pregnancy might uniquely influence sedentary time and physical activity patterns.

Chapter one introduces the rationale for the study and the general study aims.

Chapter two reviews current understandings of the effects of objectively measured sedentary time and time spent in two key sedentary behaviours, self-reported television time and occupational sitting time, in the general adult population. It then reviews the available literature concerning the prevalence and effects of sedentary time and sedentary behaviour during pregnancy, before discussing possible reasons why sedentary time (and physical activity) may have particular social meanings during pregnancy. Finally, the end of chapter two outlines the detailed aims of the study and hypotheses it aims to test.

Chapter three is a methodological literature review. It discusses the methods available for objectively measuring sedentary time and for gathering self-reported time spent in specific sedentary behaviours to identify the most appropriate methods for use in this study. It then reviews the literature concerning the processing of objectively measured accelerometry data in order to identify the most appropriate way to collect and process data concerning sedentary time in this study population.

Chapter four describes the study methodology used in this study based on the justifications presented in chapter three. It outlines the study design and protocol,

[1] The term 'behaviour' is problematic for a number of reasons that are discussed in depth in Chapter Two (section 2.8). However, 'behaviour' is used here and throughout this thesis for the sake of consistency with the literature in the broader field.

process of recruitment and data collection, data processing details, and statistical methods.

Chapters five through seven present the results of the study. Chapter five describes the sedentary time and sedentary behaviour of the study population. More specifically, the prevalence and patterning of objectively measured sedentary time are presented, as well as sociodemographic predictors of sedentary time. The prevalence and correlates of television time and occupational sitting time, as well as their association with objectively measured sedentary time, are also presented.

Chapter six tests the main hypotheses of this study, concerning the associations of sedentary time and sedentary behaviour with pregnancy outcomes, particularly gestational diabetes and glucose levels.

Chapter seven presents the thematic analyses of semi-structured interviews which aims to explore the social context of physical activity and sedentary time during pregnancy. Additionally, data concerning how participants interpreted their status of being 'at risk' for gestational diabetes, and whether that status impacted their physical activity practices, are also presented.

Finally, chapter eight discusses the main findings and conclusions of this study, including a discussion of its strengths and limitations, its implications, and potential directions for future research.

Chapter One: Introduction

Sedentary time, defined as time spent seated or reclined with low energy expenditure during waking hours (e.g., Sedentary Behaviour Research Network, 2012, Tremblay et al., 2017), has been linked to a number of poor health outcomes including all-cause and cardiovascular mortality as well as type 2 diabetes (Patterson et al., 2018). Additionally, sedentary time is associated with indicators of cardio-metabolic risk, including glucose and insulin levels, markers of insulin sensitivity, and plasma triglycerides, even after adjustment for physical activity[2] (Powell et al., 2018, Brocklebank et al., 2015), indicating that sedentary time may adversely affect physiology even in the absence of a clinically diagnosed poor health outcome (e.g., type 2 diabetes). For these reasons, the epidemiology of sedentary time has become a major subfield of physical activity research over the past decade (Yates et al., 2011, Wijndaele and Healy, 2016, Dunstan et al., 2012b, Stamatakis et al., 2018).

Television time is the most commonly measured sedentary behaviour (Mansoubi et al., 2014) and has consistently been associated with poor health outcomes, including type 2 diabetes (Biswas et al., 2015, Wilmot et al., 2012). In fact, a recent appraisal of the literature by Stamatakis et al. (2018) has highlighted that the vast majority of the evidence base concerning the detrimental effects of sitting is actually derived from evidence concerning television time, which is not necessarily a suitable proxy for total sitting time (Clark et al., 2011a, Clark et al., 2015). Recent meta-analytic findings indicate that the effect size of television time in relation to poor health outcomes including type 2 diabetes may be larger than the effect of total sitting time (Patterson et al., 2018). In contrast, links between occupational sitting time (another important source of sedentary time) and type 2 diabetes are inconsistent (van Uffelen et al., 2010, Stamatakis et al., 2017). These findings underscore the importance of objectively measuring sedentary time to understand the effects of total sitting time, while they also raise questions concerning why the effects of television time and occupational sitting time may be so different.

[2] Since the field's inception, the effects of sedentary time have been considered as 'independent' of physical activity, although recent work has suggested that the effects of sedentary time might be dependent upon physical activity levels, with sedentary time having more pronounced effects among those with low physical activity (see Stamatakis et al. (2018) for review).

The evidence base concerning the effects of sedentary time during pregnancy is scarce. Given the aetiological similarities between type 2 diabetes and gestational diabetes (i.e., both are characterised by inabilities of the pancreatic β-cells to cope with chronically high insulin and glucose levels), a link between sedentary time and gestational diabetes might be expected. However, the available evidence concerning associations between sedentary time during pregnancy and incident gestational diabetes is limited. No studies to date have tested associations between objectively measured sedentary time and incident gestational diabetes. Four studies have used various measures of self-reported sedentary time and have reported mixed results: three studies reported a null association between television time and gestational diabetes or abnormal glucose tolerance (Gollenberg et al., 2010, Oken et al., 2006, Padmapriya et al., 2017), while two studies reported positive associations between time spent sitting at home (which included television time) and gestational diabetes (Leng et al., 2016), and between a composite measure of television time plus time spent sitting at work and abnormal glucose tolerance (Gollenberg et al., 2010). Objectively measured sedentary time has been tested in association with glucose and insulin levels during pregnancy (Loprinzi et al., 2013, Hayes et al., 2014, Nayak et al., 2016, Gradmark et al., 2011); no studies reported significant associations. However, it is important to note that the objective measures of sedentary time used by these studies had major methodological limitations, primarily related to the use of accelerometers that cannot differentiate sitting from standing, which is a key distinction in the measurement of sedentary time. Thus, high-quality objective measures of sedentary time are needed to understand the associations between sedentary time during pregnancy, gestational diabetes incidence, and glucose levels.

Besides aiming to fill this gap in knowledge, there are several reasons why exploring the prevalence, effects, and context of sedentary time specifically during pregnancy is important. First, numerous biological changes take place during pregnancy, including in the regulation of glucose. All healthy pregnancies are characterised by a period of insulin resistance due to anti-insulin hormones produced by the placenta, which serve to maintain a concentration gradient of glucose to ensure the foetus is continuously nourished (Edlow and Norwitz, 2014). Given the association between sedentary time and glucose regulation among non-pregnant adults (Powell et al., 2018, Brocklebank et al., 2015), it may be especially important to understand whether

glucose metabolism during pregnancy is additionally adversely impacted by sedentary time, especially among women who are at risk for developing gestational diabetes. Second, and related to the previous point, pregnancy is associated with dramatic physical changes, both hormonally and morphologically, which may impact daily physical activity patterns. The physical activity literature often suggests these physical changes serve as 'barriers' to activity during pregnancy (see Coll et al., 2016 for review), which may implicitly suggest that sedentary time in the form of taking naps, putting swollen feet up, or sitting down to alleviate back pain might increase as pregnancy progresses. Finally, and most importantly, there may be a social expectation for women to sit or rest more during their pregnancies, which may have implications for sedentary time. To date, this has not been explored. However, a quantitative survey among pregnant women in the UK reported that 'rest and relaxation' was perceived by respondents as significantly more important during pregnancy than exercise (Clarke and Gross, 2004), suggesting that resting may have a particular meaning during pregnancy. This finding warrants further qualitative investigation into the social context of sedentary time and 'resting' during pregnancy.

This study takes a biological-anthropological approach to understand the prevalence, effects, and social context of sedentary time among pregnant women in the United Kingdom who have a risk factor for gestational diabetes. A mixed-methods approach is used to collect data on objectively measured sedentary time and self-reported time spent in specific sedentary behaviours to test associations with gestational diabetes, plasma glucose levels, and other pregnancy outcomes. These data are supplemented with semi-structured interviews which aim to explore the role of social context in women's everyday sedentary and physical activity practices during pregnancy, and to explore how women interpret being 'at risk' for gestational diabetes and whether their risk status has any additional impact on physical activity practices during pregnancy.

Chapter Two: Literature review

This chapter reviews the current understandings of the effects of sedentary time and sedentary behaviour in both the general population and specifically during pregnancy and discusses why sedentary time might have special meanings during pregnancy, to situate the aims and hypotheses that this thesis aims to address. The literature describing the associations between sedentary time/behaviour and health outcomes (sections 2.3 to 2.7) was systematically searched to gather all available and relevant evidence. Terms for sedentary time or sedentary behaviour (with appropriate wildcard and truncation symbols) were used to search Web of Science, and all studies that either reported objective measures of sedentary time or self-reported measures of television time or occupational sitting time within free-living settings in relation to relevant health outcomes (diabetes, all-cause mortality, metabolic syndrome, biomarkers of cardiovascular disease, and pregnancy outcomes) were included. Intervention studies were not included because the outcome of interest to this thesis is the effect(s) of sedentary time within free-living contexts. Studies were included in the review if they met these criteria; study details that indicate quality of the evidence (e.g., sample size, type of accelerometer used, duration of follow-up period) are provided in the text to help interpret the strength of the evidence.

2.1 Defining the terms: sedentary time, sedentary behaviour, and physical inactivity

2.1.1 Sedentary 'behaviour' versus physical inactivity

The term 'sedentary', from the Latin *sedere* ('to sit'), has been used in the field of physical activity research since its inception, usually to describe individuals who exhibit low levels of physical activity in the workplace, during leisure-time, or overall (e.g., Blair and Brodney, 1999, Paffenbarger et al., 1986, Morris et al., 1953). However, in the past decade, a subfield of physical activity research has emerged which has identified links between time spent sitting and a wide range of poor health outcomes and biomarkers, independently from physical activity (Healy et al., 2008c, Patterson et al., 2018, Koster et al., 2012). To this end, the Sedentary Behaviour Research Network proposed a redefinition of terms in 2012, suggesting that

'sedentary behaviour' be defined as 'any waking behaviour characterised by an energy expenditure less than or equal to 1.5 metabolic equivalents, while in a sitting, reclining, or lying posture' (Sedentary Behaviour Research Network, 2012). Alongside this redefinition, 'physical inactivity' now specifically refers to 'an insufficient physical activity level to meet present physical activity recommendations' (Sedentary Behaviour Research Network, 2012, Tremblay et al., 2017), usually meaning accumulating fewer than 150 minutes of moderate-to-vigorous physical activity (MVPA) per week (WHO, 2010).

The differentiation between sedentary behaviour and physical inactivity is important not only for clarifying the terms but is also an essential distinction from a physiological perspective. It is possible to have high sedentary time and also be 'sufficiently' active. Indeed, evidence from the UK and the US suggests that most adults spend the majority of their waking hours sedentary, even if physical activity recommendations are met (Craft et al., 2012, Bakrania et al., 2016). Because of this, there is ongoing interest in understanding whether high levels of MVPA might 'offset' the detrimental effects of high sedentary time (e.g., Ekelund et al., 2016), and whether minimising sedentary time without meeting MVPA guidelines (by displacing sedentary time with light physical activity) confers any cardio-metabolic benefits (e.g., Bakrania et al., 2016).

2.1.2 Sedentary behaviours in relation to sedentary time

A second key distinction to make is the difference between sedentary *behaviour* and sedentary *time*. Although the two terms are often used interchangeably in physical activity research and generally refer to the same construct of sitting or reclining, it is important to explicitly point out that sedentary *time* is defined as 'the time spent in any duration (e.g., minutes per day) or in any context (e.g., at school or work) in sedentary *behaviours*' (italics mine) (Tremblay et al., 2017). Thus, time spent in various sedentary behaviours collectively add up to total sedentary time. For this reason, throughout this thesis, 'sedentary time' refers to total time spent sitting (referring to objective measures where possible), and 'sedentary behaviour' refers to time spent sitting in a specific context (e.g., time spent watching television).

2.1.2.1 Where does sedentary time come from in everyday life?

Population-based objective measures of sedentary time in the UK, US, Canada, the Netherlands, and Australia estimate that adults spend between 8.4 and 10.8 hours sedentary per day (Healy et al., 2011b, Bakrania et al., 2016, Bellettiere et al., 2017, Carson et al., 2014, de Rooij et al., 2016).

To date, there is surprisingly scant published data that describe the everyday sedentary behaviours that comprise total sedentary time in everyday life. In terms of the prevalence of sedentary behaviours, Tudor-Locke et al. (2010) reported that, among women (n>40,000) in the US, the most commonly reported sedentary behaviours that did not take place at work were sitting to eat or drink, sitting to watch television or movies, sitting to socialise, and sitting to travel (e.g., via car) based on a past-day recall (via the American Time Use Survey). This is corroborated by a smaller-scale (n=1442) study that used past-day recall, also in the US, in which the most commonly reported sedentary behaviour was eating, followed by watching television, talking with others (including on the phone), using the computer, and reading (Kim and Welk, 2015). Thus, across both studies, the most prevalent sedentary behaviour within the US population is sitting to eat, followed by sitting to watch television.

In terms of time allocation, the largest amount of total sitting time was accumulated sitting at a non-television screen (e.g., computer), followed by administrative tasks (e.g., desk work), watching television, eating, sitting in the car, and leisure activities such as playing an instrument or painting in Kerr et al.'s (2013) sample of university employees (n=40) in the US who agreed to wear a wearable camera. Kim and Welk (2015) findings based on past-day recall among randomly-sampled adults in the US were generally similar, reporting that the largest amount of daily sitting time was amassed at the computer (138 minutes per day), followed by time spent watching television (129 minutes per day) and attending events (i.e., meetings, films, concerts; 115 minutes per day).

Taken together, the limited evidence (all from the US) that is available suggests that daily sedentary time comes from a variety of sources that are embedded in everyday life. While sitting at work and watching television seem to be highly prevalent and

extended sedentary behaviours, eating and socialising are also key sedentary behaviours that contribute to total sedentary time.

2.1.2.2 Television time and occupational sitting time

Within physical activity research, television time is the most commonly measured sedentary behaviour (Mansoubi et al., 2014, Clark et al., 2009). Television time is often a main target of sedentary behaviour epidemiology because it is the most prevalent sedentary leisure-time activity at least in some populations, including the UK (Office for National Statistics, 2017). Among adult women (aged 16 and over) in the UK, television accounts for 2.8 hours per day on average based on the 2016 Health Survey for England (Health Survey for England, 2017). This figure is broadly consistent with prevalence of television time in other population-based studies, with 1.7 hours per day reported among women in Australia (Clark et al., 2010), and 2.6 hours per day among women in the US (Keadle et al., 2017). Because of its prevalence and its occurrence within leisure time, television time is a popular target for measurement and interventions because it is assumed to be discretionary and therefore more voluntarily modifiable than other sedentary behaviours (e.g., Wijndaele et al., 2010).

Occupational sitting time is another key domain of sedentary time that has been an ongoing focus of physical activity researchers. This is in part because sitting at work has been suggested to be one of the biggest contributors to total (self-reported) sitting time among employed adults, particularly in office-based or professional jobs (Jans et al., 2007, Kazi et al., 2014). Among adults in the UK, mean self-reported time spent sitting at work across a range of occupational types has been reported as 4.5 hours per day (Kazi et al., 2014). This measure is consistent with 4.6 hours a day reported in a population-based sample of Danish adults (Aadahl et al., 2013), 3.8 hours reported by a random sample of working Australian adults (De Cocker et al., 2014), and 4.2 hours per day among a large sample of working French adults (Saidj et al., 2015).

Given the prevalence of television time and occupational sitting time in the general population and the ubiquity of the measurement of these specific domains in sedentary research, television time and occupational sitting time are sedentary behaviours of interest and are the sedentary behaviours on which this thesis focuses.

2.2 Considerations for the interpretations of measurements of sedentary time and sedentary behaviour

Before discussing the work that has been done in relation to the epidemiology of sedentary time and sedentary behaviour in both non-pregnant and pregnant populations, this section aims to briefly address several key issues concerning the measurement of sedentary time and sedentary behaviour to facilitate the interpretation of evidence presented in subsequent sections of this chapter. Although more limitations than these exist (which are detailed in Chapter Three), it is necessary to raise these issues at this point in the thesis because almost all of the existing evidence concerning sedentary time and sedentary behaviour is subject to these measurement limitations.

2.2.1 Limitations in the objective measurement of sedentary time

To date, most studies that have objectively measured sedentary time have used devices that are unable to accurately detect posture. The majority of objective studies to date have used waist-worn accelerometers (e.g., Actigraph) or arm-worn devices (e.g., SenseWear armband), which cannot reliably differentiate sitting from standing (van Nassau et al., 2015, Edwardson et al., 2016a, Reece et al., 2015). This distinction is crucial for the measurement of sedentary time.

Waist-worn accelerometers may also introduce error to measurements of sedentary time due to non-wear patterns. Most studies that use waist-worn accelerometers apply waking wear protocols in which participants are instructed to remove the accelerometer to sleep at night and for any water-based activities such as swimming or bathing. There is evidence to suggest that this may result in a substantial underestimation of sedentary time because participants are likely to remove the device in the evenings well before going to bed (Tudor-Locke et al., 2011a), which may be a portion of the day characterised by particularly high sedentary time (McVeigh et al., 2016).

A small but growing number of studies have used accelerometers that can accurately detect posture, such as the thigh-worn activPAL, which has been identified as the 'gold standard' for the measurement of sedentary time in free-living contexts (Kim et al., 2015a, Kozey-Keadle et al., 2011). The activPAL also provides an option for a

continuous (24-hour) wear protocol, which is commonly but not always used (Edwardson et al., 2016b).

Thus, while objective measures of sedentary time have higher validity than subjective measures (Atkin et al., 2012), the type of accelerometer used and its inherent measurement limitations must be considered in the interpretations of the study's findings.

2.2.2 Limitations in the subjective measurement of sedentary behaviours

Questionnaires are the most commonly used tools for the subjective measurement of total sedentary time and sedentary behaviour. Where questionnaires have aimed to capture total sedentary time, they have demonstrated poor validity in comparison to accelerometry (Atkin et al., 2012). The measurement of total sedentary time via self-report is uniquely challenging, at least partially due to the unstructured nature of most sedentary activities that make them difficult to quantify, and their often concurrent nature (e.g., working on a laptop while watching television), adding to the difficulty to estimate total sitting time (Atkin et al., 2012).

The measurements of time spent in specific sedentary *behaviours* may have higher validity. For example, self-reported television time and occupational sitting time have been demonstrated to have high criterion validity when compared with a criterion measure of activPAL-measured sitting time annotated with a daily time-use record (rho=0.84 and 0.63, respectively) (Wijndaele et al., 2014a). Thus, while self-reported measures of total sedentary time have limited validity, self-reported time spent in specific sedentary behaviours – especially those as structured as television time and sitting at work – appear to be reasonably accurate measures of sedentary time accumulated within those domains. A more detailed assessment of the validity of these measures is provided in Chapter Three (section 3.6).

While the measurement of time spent in specific sedentary behaviours is useful for understanding prevalence and patterns of time spent in specific sedentary behaviours, it is paramount to emphasise that time spent in specific sedentary behaviours cannot necessarily be extrapolated to total sedentary time. For example, evidence suggests that the correlation between television time and objectively measured sedentary time is low (Jacobi et al., 2009, Clark et al., 2011a, Clark et al.,

2015). This suggests that television time cannot be used as a proxy for total sedentary time, and the results of studies that have used television time as a predictor variable for various health outcomes should not necessarily be interpreted as health effects of sitting time (Stamatakis et al., 2018).

2.2.3 Conclusion

The evidence presented in this section highlighted the major limitations of the most common measurements of sedentary time. An accurate measurement of total sedentary time requires an objective device that is able to measure posture over an entire 24-hour period. Thus, the measurement limitations of waist-worn accelerometry (primarily inability to detect posture) must be taken into consideration when interpreting findings based on these measurements.

While the measurement of time spent in specific sedentary behaviours (e.g., television time or occupational sitting time) may be useful and valid for understanding the prevalence and patterns of those specific behaviours, these measurements cannot be extrapolated to total sedentary time. Furthermore, self-reported measures of total sedentary time have low validity and should be interpreted with caution.

Throughout the remainder of this thesis, the way in which sedentary time/behaviour was measured in each study that is discussed is explicitly stated (sometimes in brackets) to help the reader interpret the relative quality of the measurement of sedentary time used with each study.

2.3 Associations between objectively measured sedentary time and health outcomes in the general population

As discussed in the beginning of this chapter (section 2.1.2), measurements of sedentary time and sedentary behaviour are different constructions with different implications and may therefore have different impacts on health. Therefore, the effects of objectively measured sedentary time are exclusively discussed in this section[3]; the effects of time spent in sedentary behaviours is discussed in section 2.4.

[3] Effects of self-reported total sitting time are not discussed here because of the low criterion validity of this measurement compared with the activPAL accelerometer (Chastin et al., 2018)

For each included study, the accelerometer used is included in brackets to denote the relative strength of the study's measurement of sedentary time and, where appropriate, the study's odds ratios (OR), hazard ratios (HR), or relative risk (RR) with corresponding 95% confidence intervals (95%CI) are provided. Because the focus of this thesis is the association between sedentary time and gestational diabetes, evidence concerning the association between sedentary time and type 2 diabetes and indicators of glucose regulation is the focus of this section, with evidence concerning mortality and other cardio-metabolic biomarkers subsequently presented.

2.3.1 Total sedentary time

The following sections review the current evidence describing the associations between objectively measured total sedentary time (usually defined as mean hours of sedentary time across valid measurement days) and the specified outcomes.

2.3.1.1 Type 2 diabetes

To date, there is only one study to my knowledge that has examined an association between total sedentary time and development of type 2 diabetes using a prospective study design. In the US, Barone Gibbs et al. (2015) reported that sedentary time (Actigraph[4]) among a sample of adults (aged 38-50, n=2027) at baseline was not associated with the development of type 2 diabetes at follow-up 5 years later (OR 0.57 for the highest quartile of sitting compared to the lowest, no CI's provided), although the authors noted that longer follow-up may be required to capture prospective associations (Barone Gibbs et al., 2015). In the same sample, sedentary time at baseline was cross-sectionally associated with higher prevalent type 2 diabetes, in which those in the two highest quartiles of sedentary time (8-9.9 and ≥10 hours per day) had higher prevalence of type 2 diabetes compared to those in the lowest quartile (<6 hours per day) after adjustment for MVPA (OR 3.13 and 3.80 respectively; CI's not numerically provided in the study) (Barone Gibbs et al., 2015).

[4] The Actigraph can be worn on the waist, wrist, or thigh (discussed further in Chapter Three); unless otherwise noted, studies that used the Actigraph in this chapter used the waist-worn configuration.

The only other evidence concerning a link between objectively measured sedentary time and type 2 diabetes is based on two studies that used cross-sectional study designs. Among a population-based sample in the Netherlands (n=2497), sedentary time (measured by the activPAL) was associated with significantly higher odds of having type 2 diabetes (OR 1.22 (95%CI 1.13, 1.32)) after adjustment for MVPA, BMI, and other covariates (van der Berg et al., 2016a). This is corroborated by evidence from a sample of older women in the US (n=6116), in which those in the highest quartile of Actigraph-measured sedentary time (≥10.3 hours per day) had higher odds of prevalent diabetes (OR 1.71 (95%CI 1.34-2.20)) than women in the lowest quartile of sedentary time (≤8.3 hours per day) after adjustment for BMI and MVPA (Bellettiere et al., 2018). However, cross-sectional associations do not provide any information about temporal patterns, so causality cannot be determined.

In summary, there are sparse data concerning a possible link between objectively measured sedentary time and subsequent development of type 2 diabetes in the general population; the only available evidence suggests no prospective link, although a longer follow-up period and higher-quality measure of sedentary time is needed. While there is evidence to suggest that higher sitting time is associated with prevalent type 2 diabetes, the cross-sectional designs of those studies limit inferences concerning causality.

2.3.1.2 Indicators of glucose regulation

Although there is scant evidence concerning the possible prospective link between total sedentary time and incident type 2 diabetes, total sedentary time has been linked to a number of indicators of poor glucose regulation in cross-sectional studies (see Table 2.1 for detailed summary). These include higher fasting glucose levels (Powell et al., 2018), higher 2-hour plasma glucose (Bellettiere et al., 2017, Henson et al., 2013a), and higher fasting insulin (Barone Gibbs et al., 2015, Swindell et al., 2018, Carson et al., 2014, Powell et al., 2018, Healy et al., 2011b). Furthermore, total sedentary time is linked to indicators of insulin resistance such as HOMA-IR (Barone Gibbs et al., 2015, Swindell et al., 2018), indicators of β-cell function such as HOMA-%B (Healy et al., 2011b), and indicators of insulin sensitivity such as HOMA-%S (Healy et al., 2011b). Importantly, where studies have controlled for MVPA (Barone Gibbs et al., 2015, Swindell et al., 2018, Healy et al., 2011b, Henson et al., 2013a, Carson et al., 2014) and BMI or other indicator of adiposity (Barone Gibbs et al., 2015,

Swindell et al., 2018, Henson et al., 2013a), these associations have persisted, indicating that total sedentary time may have an independent effect on glucose metabolism. Therefore, despite the lack of available evidence to date concerning the prospective link between sedentary time and development of type 2 diabetes, there is evidence to suggest that sedentary time impacts the way in which the body metabolises glucose.

Table 2.1 Summaries of studies examining cross-sectional associations between objectively measured sedentary time and markers of glucose metabolism in adult populations

Study	Sample	Measurement of sedentary time	Outcome variable	Association with sedentary time	Covariates included in model
Powell et al. (2018)	Meta-analysis	All included studies used objective measures	Fasting glucose	Δ=0.12 (95%CI 0.03, 0.23)	Unadjusted effect sizes were extracted from papers where possible
			Fasting insulin	Δ=0.19 (95%CI 0.06, 0.32)	
Belletierre et al. (2017)	Population-based Australian sample of adults aged ≥25 (AusDiab study), n=678	activPAL		Mean difference for lowest quintile sitting time versus highest	Wear time, age, gender, ethnicity, smoking status, marital status, family history of diabetes, housing time, height, calcium intake
			Fasting glucose	-0.13 (-0.35, 0.10); p for trend = 0.07	
			2-hour glucose	-0.50 (-0.85, 0.14); **p for trend = 0.01**	
Henson et al. (2013)	Adults at risk for Type 2 diabetes in the UK (n=878)	Actigraph GT3X (waist-worn)		β, p-value	Age, sex, smoking status, ethnicity, social deprivation, family history, wear time, **MVPA, BMI**
			Fasting glucose	0.01, p=0.86	
			2-hour glucose	**0.22, p<0.001**	
Barone Gibbs et al. (2015)	Adults in the US (CARDIA study), n=2027	Actigraph 7164 (waist-worn)		β, p-value	Age, study site, race, sex, education, income, smoking, alcohol, wear time, **MVPA, BMI,** hypertension, diabetes
			Fasting glucose	-0.10, p=0.56	
			2-hour glucose	0.0, p=0.93	
			Fasting insulin	**2.0, p=0.007**	
			HOMA-IR	**1.9, p=0.02**	
Swindell et al. (2018)	Overweight adults with prediabetes in 8 countries (n=2326)	Actigraph, waist-worn (24-hour wear protocol)		β (95%CI), p-value	Age, sex, ethnicity, smoking, household income, education, **body fat percentage**, wear time, sleep time, **MVPA**
			Fasting glucose	0.05 (-0.01, 0.11), p>0.05	
			2-hour glucose	0.05 (-0.01, 0.11), p>0.05	
			Fasting insulin	**0.13 (0.06, 0.10), p<0.01**	
			HOMA-IR	**0.15 (0.08, 0.21), p<0.001**	
Carson et al. (2014)	Nationally representative sample of Canadian adults (2007-11 Canadian Health Measures Survey), n=2551 for fasting subsample	Actical (waist worn)		β (95%CI), p-value	Age, sex, income, smoking alcohol use, medical history (of type 2 diabetes or other CVD), **MVPA**
			Fasting glucose	0.002 (-0.002, 0.005), p>0.05	
			Fasting insulin	**0.022 (0.003, 0.042), p<0.05**	
Healy et al. (2011)	Nationally representative sample of American adults (2003-6 NHANES cycle), n=2118 fasting subsample, n=910 did OGTT	Actigraph 7164 (waist-worn)		P for trend of quartiles of sedentary time	Age, sex, ethnicity, **MVPA,** wear time
			Fasting glucose	0.87	
			2-hour glucose	0.12	
			Fasting insulin	**<0.001**	
			HOMA-%B	**<0.001**	
			HOMA-%S	**<0.001**	

2.3.1.3 All-cause and cardiovascular mortality

Two studies have examined a prospective link between objectively measured sedentary time and all-cause mortality. Using data from the 2003-4 NHANES[5] cycle, Koster et al. (2012) reported that higher objectively measured (Actigraph) sedentary time at baseline was associated with higher odds of mortality (for the highest quartile of sedentary time versus the lowest) at follow-up 2.8 years later (HR 3.26 (95%CI 1.59-6.69)), after adjustment for BMI, MVPA, and other covariates, suggesting that total sedentary time is associated with incident all-cause mortality. This is corroborated by population-based findings from Sweden (n=851) in which those in the highest tertile of sedentary time (Actigraph) at baseline had higher odds of all-cause (HR 2.72 (95%CI 1.40, 5.30), cardiovascular (HR 5.51 (95%CI 1.43, 21.23), and cancer (HR 4.34 (95%CI 1.18, 16.03) mortality over 15 years of follow-up, after MVPA was controlled (Dohrn et al., 2018). Thus, there is evidence for a link between objectively measured sedentary time and incident mortality that persists after adjustment for MVPA.

2.3.1.4 Metabolic syndrome

The metabolic syndrome is defined as a cluster of interrelated risk factors for cardiovascular disease and type 2 diabetes. While the specific diagnostic criteria vary, the metabolic syndrome is generally defined as the presence of at least three of the following criteria: elevated waist circumference, high triglycerides, low HDL cholesterol, high blood pressure, and elevated fasting glucose (Grundy et al., 2005).

To date, one study has examined a longitudinal association between sedentary time and clustered metabolic risk score (calculated based on measures of waist circumference, cholesterol, blood pressure, fasting glucose, and insulin) among adults (n=171) in the UK at risk of type 2 diabetes due to family history (Wijndaele et al., 2014b). Sedentary time (Actigraph) and clustered metabolic risk were measured at both baseline and follow-up 6 years later; increased sedentary time over that time period was associated with increased clustered cardio-metabolic risk (*b*=0.08 (95%CI

[5] The National Health and Nutrition Examination Survey (NHANES) is a population-based study in the US that cross-sectionally measures a variety of health-related exposure and outcome variables of around 5000 individuals each year. The subset of NHANES data used in studies cited within this thesis concern objective or self-reported measures of sedentary behaviour and/or physical activity, sometimes in relation to biomarkers also collected within the study.

0.01, 0.15)) after adjustment for baseline sedentary time, baseline and change in MVPA, and other covariates (Wijndaele et al., 2014b).

This longitudinal finding is generally corroborated by a cross-sectional analysis using data from the 2003-6 NHANES cycle. Among adults 60 years and older (n=1367), those who spent a higher proportion of Actigraph wear time sedentary had greater likelihood of metabolic syndrome (p=0.04 for trend) after adjustment for BMI, MVPA, and other covariates (Bankoski et al., 2011).

In summary, there is some evidence for a prospective link between sedentary time and the development of the metabolic syndrome, which is supported by cross-sectional evidence.

2.3.1.5 Biomarkers of cardio-metabolic health

Objectively measured sedentary time has been tested in relation to a broad range of biomarkers of cardio-metabolic health including plasma triglycerides, high-density lipoprotein (HDL) and low-density lipoprotein (LDL) cholesterol, BMI and waist circumference, blood pressure, and markers of inflammation such as C-reactive protein and interleukin-6. The links between objectively measured sedentary time and each of these biomarkers (except for inflammation) have been summarised in a systematic review (Brocklebank et al., 2015) and a meta-analysis (Powell et al., 2018); for brevity, the findings of these reviews are summarised here, followed by a brief summary of the literature concerning inflammation. For associations between sedentary time and indicators of glucose regulation, refer back to section 2.3.1.2.

In the systematic review by Brocklebank et al. (2015), 22 studies that examined associations between accelerometer-measured sedentary time and total cholesterol, HDL-cholesterol, LDL-cholesterol, and triglycerides were included[6]. They reported evidence of a positive association between total sedentary time and triglycerides, based on 12 of 18 cross-sectional studies (9 adjusted for MVPA and 3 adjusted for adiposity). Associations between sedentary time and HDL-cholesterol were inconsistent: 9 of 20 cross-sectional studies reported a negative association (8 adjusted for MVPA and 4 adjusted for adiposity). Generally, null associations

[6] The remaining studies included only measures of glucose metabolism which are not discussed here

between sedentary time and total cholesterol or LDL cholesterol were reported in the review (Brocklebank et al., 2015).

The systematic review by Powell et al. (2018) included 46 cross-sectional studies that tested associations between objectively measured sedentary time and body mass, body composition, HDL cholesterol, LDL cholesterol, triglycerides, systolic and diastolic blood pressure, with meta-analysis done for waist circumference, HDL cholesterol, triglycerides, and fasting glucose and insulin (described previously in section 2.3.1.2). Based on the meta-analysis, increased sedentary time was associated with increased waist circumference (Δ=0.25 (95%CI 0.15, 0.35), p<0.001), decreased HDL cholesterol (Δ=-0.20 (95%CI -0.28, -0.13), p<0.001), and increased triglycerides (Δ=0.25 (95%CI 0.14, 0.37), p<0.001), although it should be noted that unadjusted values from the included studies were pooled in the meta-analysis due to the variation in covariates included in the adjusted models of the papers (thus, physical activity and BMI were not controlled). The narrative synthesis of the studies that investigated the remaining outcome variables of interest indicate that associations with BMI, blood pressure, and LDL cholesterol, are mixed; many studies reported null associations for each, or reported significant associations with sedentary time that were attenuated when MVPA was adjusted (Powell et al., 2018).

Neither of these systematic reviews included markers of inflammation (e.g., C-reactive protein (CRP) or interleukin-6 (IL-6)) as an outcome of interest, despite the fact that inflammation is associated with the development of cardiovascular disease and type 2 diabetes (Calle and Fernandez, 2012). To my knowledge, only two studies have tested associations between objectively measured sedentary time and markers of inflammation in adult populations that are not characterised by a pathology such as type 2 diabetes or the metabolic syndrome. Using data from the 2003-6 NHANES cycle (n=4757), Healy et al. (2011b) reported an association between Actigraph-measured sedentary time and CRP after adjustment for exercise (p=0.03). In a sample of adults (n=558) at risk for type 2 diabetes, Henson et al. (2013b) reported a positive association between Actigraph-measured sedentary time and levels of IL-6 (β=0.21, p=0.003), but this association was attenuated after adjustment for MVPA and BMI.

In summary, there is evidence of associations between objectively measured sedentary time and plasma triglycerides, HDL-cholesterol, and waist circumference. There is inconsistent evidence concerning the effect of sedentary time on markers of inflammation, depending upon what variables are adjusted. There is generally no evidence for an association between sedentary time and total cholesterol or LDL cholesterol.

2.3.1.6 Summary

This section has reviewed the available evidence that has reported the effects of objectively measured sedentary time on cardio-metabolic markers of health. Sedentary time is associated with adverse fasting and 2-hour glucose levels, fasting insulin levels, indicators of insulin resistance, and indicators of β-cell function. There is also evidence indicating that total sedentary time has unfavourable associations with plasma triglycerides, HDL-cholesterol and waist circumference. Where adjustments for MVPA and BMI were available, these associations generally persisted.

The associations between objectively measured sedentary time and poor health outcomes including type 2 diabetes, metabolic syndrome, and mortality are less well-established, due to the few studies that have addressed these associations, especially using a prospective study design. Cross-sectional analyses suggest that higher sedentary time is associated with higher prevalence of type 2 diabetes, but causality is unclear.

2.3.2 Distribution of sedentary time

There is evidence to suggest that, in addition to the effects of total sedentary time, the way in which sedentary time is accumulated throughout the day may have an additional impact, particularly on glucose metabolism.

The seminal paper by Healy et al. (2008a) among a subsample (n=168) of the Australian Diabetes, Obesity and Lifestyle population-based study suggested that a greater number of breaks in sedentary time (Actigraph) was associated with significantly lower 2-hour plasma glucose, lower plasma triglycerides, lower waist circumference, and lower BMI. This beneficial association with breaks in sedentary time was independent of total sedentary time and MVPA, suggesting that frequently

interrupting sedentary time by standing or moving may attenuate some of the effects of total sedentary time (Healy et al., 2008a).

Since this paper's publication, other studies have similarly demonstrated the beneficial effect of breaks in sedentary time in free-living studies among a variety of sample populations. In the population-based Canadian Health Measures Study, Carson et al. (2014) showed that breaks in sedentary time (Actical[7]) were associated with lower fasting glucose, fasting insulin, fasting triglycerides, systolic blood pressure, and waist circumference, after adjustment for total sedentary time and MVPA. Among individuals diagnosed with type 2 diabetes, breaks in sedentary time (Actigraph) were associated with improved fasting glucose and lower HOMA-IR after adjustment for MVPA (Sardinha et al., 2017). However, it should be noted that not all population-based studies have detected such beneficial effects of breaks. Bellettiere et al. (2017) reported that breaks in sedentary time (activPAL) were only beneficially associated with BMI and waist circumference; associations with triglycerides, cholesterol, blood pressure, and glucose levels were not significant. Healy et al. (2011b) reported that breaks in sedentary time (Actigraph, NHANES) were associated with improved waist circumference and levels of C-reactive protein, but found no associations with blood pressure, cholesterol, fasting triglycerides, or indicators of glucose metabolism.

Several studies have measured the effects of prolonged sedentary time (i.e., sedentary time accumulated in an uninterrupted bout lasting 20 or 30 minutes). The underlying rationale is the same as that for breaks in sedentary time – that sitting for uninterrupted periods of time may have detrimental effects. The most robust evidence for the detrimental effects of prolonged sitting time on markers of cardiometabolic health comes from laboratory-based experimental studies. In a landmark cross-over trial by Dunstan et al. (2012a), postprandial glucose and insulin levels were significantly lower following treatment conditions in which sitting time was interrupted with light or moderate activity for 2 minutes every 20 minutes compared to the condition in which sitting was uninterrupted over a 5-hour period. These findings have been replicated in studies using similar protocols (see Chastin et

[7] The Actical (Phillips-Respironics, Oregon, USA) is an accelerometer similar to the Actigraph that can be worn in waist- or wrist-worn configurations. The waist-worn configuration was used in this study.

al., 2015a for review). Among the few free-living studies that have included prolonged sedentary time as a predictor variable, prolonged sedentary time (usually defined as ≥30 minutes but ≥20 minutes in one case) had no association with fasting glucose among individuals with type 2 diabetes (Healy et al., 2015, Falconer et al., 2015) or among nationally representative samples (Carson et al., 2014, Bellettiere et al., 2017); additionally, no association between prolonged sedentary time and 2-hour glucose has been reported (Bellettiere et al., 2017).

Taken together, there is evidence to suggest that the way in which sedentary time is accumulated impacts glucose metabolism. Breaking up sedentary time is associated with improved glucose metabolism, while continuously sitting for long periods of time has the opposite effect. While this effect is most pronounced in laboratory-based settings, it has been detected in free-living studies, particularly when it is measured as breaks in sedentary time.

2.3.3 Compositional models

Thus far, the evidence presented in this thesis has been based on 'traditional' statistical models widely used within physical activity research in which the 'independent' effects of sedentary time on health outcomes are ascertained by controlling for MVPA and other covariates. However, this approach does not account for the finite nature of time use; each 24-hour period is allocated to sleep, sedentary time, light physical activity, and MVPA, and time spent in one activity (e.g., sedentary time) necessarily displaces time spent in another (e.g., MVPA). While this interdependence between physical activity categories has long been recognised (e.g., Dunstan et al., 2012b), it has generally been assumed that it was not statistically possible to account for all four physical activity categories without introducing multicollinearity (see van der Ploeg and Hillsdon, 2017), which is a violation of the assumptions of parametric statistics.

Recently, several research groups have drawn upon the application of compositional models to address this problem (Chastin et al., 2015b, Pedisic et al., 2017, Dumuid et al., 2017). Compositional models have been widely used in other fields that regularly encounter data that are composite in nature (e.g., nutrition and geology). The mathematical details of compositional models are detailed in Chapter Four (section 4.8.8). In short, the components of the composition (e.g., sedentary time, light

physical activity, MVPA, and sleep) are mathematically transformed in a way that preserves the relative magnitude of each variable in a way that is not collinear with the others. This way, sleep, sedentary time, light physical activity, and MVPA can all be entered as predictors in a regression model simultaneously, and the effect of time spent in each component relative to the other components on a given outcome can be statistically measured. Furthermore, if the 24-hour composition as a whole is significantly associated with a given outcome, the theoretical effects of reallocating time within the composition (e.g., taking 10 minutes away from MVPA and adding them to sedentary time) can be modelled, providing further insights into the relative effects of each compositional component.

While the relevance of compositional models for physical activity research is gaining momentum and may become the way forward (Pedisic et al., 2017), few studies have applied this technique to date. The vast majority of available studies that have used compositional analyses have focused on links between 24-hour time use and indicators of body composition (e.g., adiposity, waist circumference, BMI) or cardiorespiratory fitness (Dumuid et al., 2017, Dumuid et al., 2018, Fairclough et al., 2017). To date and to my knowledge, only two studies have examined associations between the composition and biomarkers of cardio-metabolic health among samples of children (Carson et al., 2016) and adults (Chastin et al., 2015b). Chastin et al. (2015b) compositionally analysed data from the 2005-6 NHANES cycle (Actigraph) and 'traditionally' analysed data from the same data set for comparison. In the 'traditional' model, sedentary time was significantly associated with BMI, waist circumference, HDL-cholesterol, plasma triglycerides, plasma insulin, and insulin resistance (HOMA) (without adjustment for MVPA); however, in the compositional model, sedentary time (relative to time spent in sleep, light PA, and MVPA) was only significantly associated with BMI and waist circumference. The composition as a whole was significantly associated with BMI, waist circumference, systolic and diastolic blood pressure, triglycerides, C-reactive protein, plasma glucose, plasma insulin, and HOMA. In predictive models in which components of the composition were reallocated, the effects were asymmetrically detrimental when sedentary time displaced MVPA (Chastin et al., 2015b). Overall, these results indicate that the effect of sedentary time is less prominent within the compositional models (presumably because the effects of sleep, LPA, and MVPA are also being taken into account) but

that the effect of sedentary time is particularly detrimental if it displaces time spent in MVPA.

2.3.4 Possible mechanisms for the effects of sedentary time

Work in the fields of biochemistry and cellular biology has proposed several possible mechanisms by which sedentary time may influence glucose metabolism and the regulation of other biomarkers. In each of these cases, the lack of skeletal muscle contractions during sedentary time has been implicated as the main issue. First, the activity of GLUT-4, a transport protein involved in the uptake of glucose from the blood, is stimulated by skeletal muscle activity. When large demands are placed on skeletal muscles, GLUT-4 is up-regulated and uptakes more glucose from the blood; in periods of inactivity, however, the expression of GLUT-4 is decreased, usually resulting in higher levels of glucose left in the blood (Huang and Czech, 2007). This may serve to at least partially explain the link between sedentary time and glucose metabolism. Second, a lack of muscular contraction for an extended period of time reduces the activity of lipoprotein lipase (LPL), an enzyme that works with circulating lipoproteins to break down triglycerides (Hamilton et al., 2004, Hamilton et al., 2007). Reductions in LPL activity due to sedentary time have been associated with significantly higher levels of serum triglycerides (Bey and Hamilton, 2003), a known risk factor for cardiovascular disease (Nordestgaard and Varbo, 2014). Finally, prolonged sitting has long been associated with an increased risk of deep vein thrombosis (DVT), the formation of blood clots in the veins (usually within the legs) which can become fatal if the clot travels to the lungs (pulmonary embolism) (Ford and Caspersen, 2012). Therefore, there is evidence that sedentary time fundamentally affects physiology, with suggestions based on evidence at the cellular level providing plausible explanations for the effects of sedentary time seen at the epidemiological level.

2.3.5 Conclusion

There is scant evidence detailing associations between objectively measured total sedentary time and poor health outcomes (type 2 diabetes, all-cause mortality). Most evidence is cross-sectional, and studies that have used longitudinal designs have had short follow-up periods which may fail to catch the incidence of these outcomes. However, total sedentary time clearly has effects on indicators of glucose

metabolism as well as the regulation of other biomarkers such as plasma triglycerides and HDL cholesterol. The way in which sedentary time is accumulated throughout the day (i.e., frequently broken up or prolonged) may additionally impact the effects of sedentary time on glucose metabolism and other cardio-metabolic outcomes. Although evidence is sparse, data from compositional models suggests that the effect of sedentary time may be attenuated when 24-hour time use is accounted for, and that sedentary time may be most detrimental if it offsets time spent in MVPA.

2.4 Associations between sedentary behaviours and health outcomes in the general population

While it is ideal to objectively measure sedentary time to understand the health effects of sitting, most of the evidence concerning the effects of 'sitting' is derived from self-reported time spent in specific sedentary behaviours, primarily television time (Stamatakis et al., 2018). Given the prevalence of television time and occupational sitting time both in the general population and within physical activity research (refer to section 2.1.2.2), evidence concerning the health outcomes of television time and occupational sitting time are described in the following sections.

2.4.1 Television time

Television time is the most commonly measured sedentary behaviour that has been tested in association with health outcomes (Mansoubi et al., 2014, Clark et al., 2009). Television time has repeatedly and consistently been linked with a range of poor health outcomes using prospective study designs, including all-cause and cardiovascular mortality (Dunstan et al., 2010, Wijndaele et al., 2010, Matthews et al., 2012a, Ekelund et al., 2016), type 2 diabetes (Dunstan et al., 2004, Ford et al., 2010, Hu et al., 2003) and cardiovascular disease (Wijndaele et al., 2011). Three meta-analyses have pooled the effects of studies examining the links between television time and type 2 diabetes, reporting a hazard ratio of 1.91 (95%CI 1.64-2.22) with adjustment for physical activity (Biswas et al., 2015), a risk ratio of 2.12 (95%CI 1.61-2.78) with inconsistent adjustment for physical activity (Wilmot et al., 2012), and a

risk ratio of 1.13 (95%CI 1.08-1.18) with adjustment for dietary factors and BMI (Grontved and Hu, 2011)[8].

A recent meta-analysis by Patterson et al. (2018) separately pooled the effects of television time and total sitting time (mostly self-reported) in relation to mortality (all-cause, cardiovascular, and cancer) and type 2 diabetes, with adjustment for physical activity (education or income was controlled in 8 of 11 studies). While television time and total sitting time were both associated with increased risk of mortality and type 2 diabetes, the effect size of television time was larger (Patterson et al., 2018). This finding is consistent with a previous meta-analysis by Ekelund et al. (2016) that suggested that not only is the strength of the association between television time and all-cause mortality stronger than the association with daily sitting time, but also that high levels of MVPA only attenuated the effect of total sitting time, not television time. The findings of these meta-analyses are broadly consistent with studies that have compared the effects of television time and another measure of sedentary time/behaviour within the same sample (see detailed summary in Table 2.2), and reported that the effect of television time in relation to cardio-metabolic risk factors or diabetes outcomes is larger and more consistent than the effect of total objectively measured sedentary time (Stamatakis et al., 2012a, Stamatakis et al., 2012b) or time spent sitting in other domains (Saidj et al., 2013, Pinto Pereira et al., 2012, Hu et al., 2003, Whitaker et al., 2018, Wennman et al., 2016, Matthews et al., 2012a).

[8] Indicators of socioeconomic position were inconsistently controlled in the studies included in these meta-analyses: education was controlled in 3/5 of the studies in Biswas et al. (2015), in 6/10 of the studies in Wilmot et al. (2012), and in 2/4 studies in Grontved and Hu (2011).

Table 2.2 Summary of studies in which television time and another indicator of sedentary behaviour/time were concurrently measured in relation to health outcomes among adult samples. Non-significant associations are greyed to visually facilitate comparison.

Study	Study sample	Outcome variable(s)	Television time	Occupational sitting time	Objectively measured sedentary time	Model covariates (indicators of physical activity, adiposity, and socioeconomic position are bolded)
Hu 2003	Women (n=68,497) in the US employed as registered nurses (Nurse's Health Study)	Type 2 diabetes	RR (95% CI) 1.70 (1.20, 2.43)	RR (95% CI) 1.48 (1.10, 2.01)		Age, **LTPA**, family history of diabetes, dietary factors, smoking, alcohol consumption, hormone use
Pinto Pereira 2012	Adults (n=7660) in the UK in paid employment (British birth cohort); results shown separately so women's (n=3712) results shown here *Biomarker data presented graphically (not numerically) so significance summarised here*	Blood pressure	NS	NS		**LTPA, BMI**, dietary factors, **social class at birth and in adulthood, education,** alcohol consumption, hormone use (met syndrome model not adjusted for BMI)
		Total cholesterol	Significant	NS		
		Triglycerides	Significant	NS		
		Hb1Ac	NS	NS		
		C-reactive protein	Significant	NS		
			OR (95% CI)	OR (95% CI)		
		Metabolic syndrome	1.30 (1.14, 1.47)	1.02 (0.93, 1.12)		
		Hypertension	1.03 (0.93, 1.14)	1.04 (0.96, 1.13)		
Saidj 2013	Working adults (n=3471) from a population-based sample in Copenhagen		p-value	p-value		**MVPA**, age, sex, **education**, smoking, alcohol consumption, dietary factors
		Waist circumference	<0.001	0.08		
		BMI	<0.001	0.08		
		Total cholesterol	0.03	0.60		
		Triglycerides	<0.001	<0.001		
		Insulin	<0.001	<0.001		
		Fasting glucose	0.09	0.10		
Stamatakis 2012a	Adults aged ≥60 (n=2765) in England, Health Survey for England; n=649 had accelerometry data		*b* (95%CI)		*b* (95%CI)	Self-reported **MVPA** or objectively measured **MVPA**, employment status, **education**, dietary factors, alcohol consumption, smoking, age, sex
		BMI	0.16 (0.10, 0.22)		0.16 (-0.02, 0.34)	
		Waist circumference	0.42 (0.28, 0.56)		0.63 (0.17, 1.09)	
		Cholesterol ratio (total:HDL)	0.02 (0.01, 0.04)		0.06 (0.00, 0.12)	
		Hb1Ac	0.01 (-0.01, 0.04)		0.01 (-0.02, 0.04)	
Stamatakis 2012b	Adults (n=11851) aged 16-65 in England; a subset of		*b* (95%CI)		*b* (95%CI)	
		BMI	0.06 (0.04, 0.07)		-0.03 (-0.06, 0.01)	

	n=1150 provided accelerometry data (Health Survey for England)	Waist circumference	0.13 (0.09, 0.17)		0.01 (-0.09, 0.10)	**MVPA, social class,** occupational status, dietary factors, smoking, alcohol consumption
		Systolic BP	0.07 (0.03, 0.12)		-0.02 (-0.09, 0.10)	
		Diastolic BP	0.05 (0.02, 0.08)		0.06 (-0.04, 0.16)	
		Total cholesterol	0.004 (0.001. 0.008)		0.01 (0.001, 0.02)	
		Hb1Ac	0.00 (-0.01, 0.01)		0.00 (-0.01, 0.01)	
Whitaker 2018	Adults in the US (n=3211), CARDIA study		β (95%CI)	β (95%CI)		**MVPA**, age, sex, ethnicity, **education**, unemployment health insurance, smoking, alcohol consumption, dietary factors, **BMI**
		Cardiometabolic risk score (measured as the sum of waist circumference, blood pressure, fasting glucose, insulin, triglycerides, HDL cholesterol divided by 6 to obtain a z-score)	0.09 (0.06, 0.11)	0.03 (-0.01, 0.07)		
Wennman 2016	Adults aged 25-74 (n=10,185) in population-based Finnish sample (National FINRISK 2007 and 2012 surveys); data were analysed separated by sex; women's data presented here	Framingham risk score, which is measured as a percentage risk for total CVD within the next 10 years (based on age, systolic blood pressure, HDL cholesterol, diabetes, smoking, and use of blood pressure medication)	% risk (95%CI)	% risk (95%CI)		**BMI**, **LTPA**, age, **education**, employment status (in TV model)
			4.18% (3.98, 4.40) in ≥4 hours group; none is 3.98% (3.74, 4.23)), p for trend <0.001	3.03% (2.90, 3.17) in ≥7 hours; none is 3.10% (2.94, 3.27), p for trend =0.58		

Discussions of possible explanations for the larger detrimental effect of television time compared to total sedentary time and time spent sitting in other domains are ongoing and still speculative. Many have suggested that snacking while watching television may contribute to its association with poor cardio-metabolic outcomes (Patterson et al., 2018, Whitaker et al., 2018, Stamatakis et al., 2012a, Stamatakis et al., 2012b, Dunstan et al., 2010, Hu et al., 2003, Saidj et al., 2013, van der Ploeg and Hillsdon, 2017, Ekelund et al., 2016), although there is no evidence available to support this suggestion. Another suggestion is that the type of sitting associated with television may be what makes it detrimental. For example, some have suggested that the timing of television watching (usually at night) may interfere with postprandial glucose metabolism (Patterson et al., 2018, Ekelund et al., 2016), that television time may be particularly prolonged in nature (Patterson et al., 2018, Saidj et al., 2013, van der Ploeg and Hillsdon, 2017, Ekelund et al., 2016), or that television time may be associated with especially low levels of muscular activation or energy expenditure compared to other sedentary behaviours such as driving or typing (Whitaker et al., 2018, Saidj et al., 2013, Pinto Pereira et al., 2012).

A key factor that is often absent from these discussions is the fact that television time is strongly socially patterned (Stamatakis et al., 2018). It has been repeatedly shown that higher television time is concentrated among those in lower socioeconomic positions as indicated by lower household income (Bowman, 2006, Shields and Tremblay, 2008, Stamatakis et al., 2009, Burton et al., 2012a), higher neighbourhood deprivation (Stamatakis et al., 2009), lower educational attainment (Teychenne et al., 2012, Van Dyck et al., 2011, Bowman, 2006, Shields and Tremblay, 2008, Clark et al., 2010, Stamatakis et al., 2009, Stamatakis et al., 2014, Huffman and Szafron, 2017), or not being in paid work (Bowman, 2006, Burton et al., 2012a, Shields and Tremblay, 2008, Clark et al., 2010, Huffman and Szafron, 2017). Since relative socioeconomic deprivation is a well-established correlate of poor health outcomes (Braveman et al., 2011) including type 2 diabetes (van Zon et al., 2017, Agardh et al., 2011), and since differences in 'health behaviours' do not fully attenuate this association (Petrovic et al., 2018), the social patterning of television time is a crucial (and possibly confounding) factor to consider. While the studies examining the effects of television time as described in this section often (but not always; see footnote on page 23) controlled for socioeconomic indicators such as education, this may not fully account for socioeconomic effects.

In summary, although television time is indeed a sedentary behaviour, its associations with poor health outcomes are more pronounced than the effects of total sedentary time. This difference may be to do with specific attributes of the nature of television time (i.e., snacking, timing, prolonged nature) or may simply represent the underlying socioeconomic gradient of television time that has not been fully accounted for in analyses.

2.4.2 Occupational sitting time

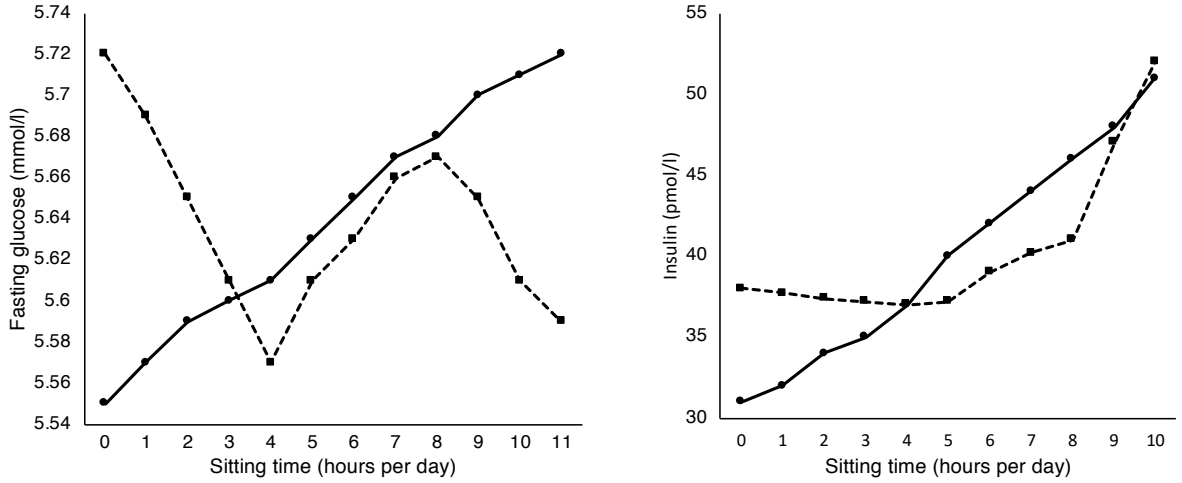
On average among working adults, nearly one third of the 24-hour weekday is spent at work (Tudor-Locke et al., 2011b). Data from the US suggest that occupational physical activity has declined over the past half-century with the increase in sedentary, service-related occupations (Church et al., 2011, Ng and Popkin, 2012). Accelerometry studies have indicated that among office and call-centre workers, over 70% of working hours are spent sitting (Parry and Starker, 2013, Thorp et al., 2012, Toomingas et al., 2012, Clemes et al., 2014). For this reason, the workplace (particularly office-based settings) has been a recent target for interventions to reduce sedentary time (e.g., Dunstan et al., 2013).

Despite the volume of daily sedentary time that is often accumulated while sitting at work, the associations between occupational siting time and poor health outcomes are surprisingly weak. A systematic review in 2010 indicated that there were inconsistent associations between occupational sitting time and mortality, cardiovascular disease, type 2 diabetes and cancer (van Uffelen et al., 2010). Since then, results of additional studies have suggested that the effects of occupational sitting time are tenuous. For example, among the Whitehall II cohort in the UK, self-reported occupational sitting time at baseline had no association with incident type 2 diabetes after 13 years of follow-up, regardless of whether other factors such as MVPA, employment grade, smoking, alcohol consumption, and other factors were controlled (Stamatakis et al., 2017). Similarly, self-reported occupational sitting time at baseline had no association with all-cause mortality over 12 years of follow-up, after adjustment for BMI, leisure-time physical activity (LTPA), and social class among Danish employees (150,000 person-years of observation) (van der Ploeg et al., 2015). Among women (n=5380, drawn from seven Health Survey for England and Scottish Health Survey cohorts), those with predominantly standing/moving jobs

had decreased likelihood of all-cause (HR 0.68 (95%CI 0.52, 0.89)) and cancer (HR 0.60 (95%CI 0.43, 0.85)) mortality but not cardiovascular mortality (HR 1.53 (95%CI 0.72, 3.24)) compared to those with predominantly seated occupations, after adjustment for waist circumference, LTPA, and education (Stamatakis et al., 2013).

The marginal and inconsistent effects of occupational sitting time are most apparent when associations of occupational sitting time and television time with cardio-metabolic biomarkers are presented within the same sample. The details of these studies can be found in Table 2.2 and are summarised here. Pinto Pereira et al. (2012) reported that, after adjustment for BMI, LTPA, education, and social class at birth and adulthood, television time was associated with diastolic blood pressure, total cholesterol, triglycerides, HDL cholesterol, and CRP among British women in paid work; in contrast, occupational sitting time was not associated with any of these biomarkers after adjustment for the same covariates. Similarly, Saidj et al. (2013) reported significant linear associations between leisure-time sitting (including television time) and waist circumference, body fat, HDL cholesterol, triglycerides, insulin, LDL cholesterol, total cholesterol, and BMI, after adjustment for MVPA and education among Danish working adults; in contrast, occupational sitting time was associated only with HDL cholesterol, triglycerides, and insulin. Interestingly, the findings of Saidj et al. (2013), reproduced in plots below (Figure 2.1), show negative or flat associations between occupational sitting and fasting glucose and insulin until around ≥5 hours per day, in contrast to leisure-time sitting which is generally linear. Taken together, the associations between occupational sitting and cardio-metabolic biomarkers are inconsistent and are in stark contrast to the consistent associations with television time.

Figure 2.1. Associations between leisure-time sitting (including television time, solid line) and occupational sitting time (dotted line) and fasting glucose (left) and insulin (right) levels; graphs adapted from data in Saidj et al. (2013).



As with television time, it is important to point out the possible explanations that may underlie the comparatively weak and inconsistent associations with occupational sitting time. One explanation may be that the nature of occupational sitting may be different than other types of sitting (especially television time). In their paper's discussion, Saidj et al. (2013) suggested that occupational sitting may be more frequently interrupted than television time. This may be supported by a study of office workers in London, in which workers averaged around 3 sit-to-stand transitions per hour (measured by the activPAL) during working hours (Smith et al., 2015), suggesting that sitting time at work may be regularly interrupted. However, Parry and Starker (2013) and Thorp et al. (2012) both reported that, among both office-based workers (Parry and Starker, 2013) and a mixture of occupational types (Thorp et al., 2012), a greater proportion of prolonged sedentary time (sedentary time in bouts lasting ≥30 minutes) across the entire measurement period was accumulated during working hours (Parry and Starker, 2013, Thorp et al., 2012) or on working days (Parry and Starker, 2013) compared to periods not at work. Thus, while it is not known how the accumulation of sedentary time at work directly compares to the accumulation while watching television, this evidence suggests that occupational sitting time is often prolonged in nature. Pinto Pereira et al. (2012) suggested that occupational sitting may have higher energy expenditure than television time, which may attenuate some of the effects of occupational sitting; although this is possible, its explanatory power is still based on speculation.

Most commonly, authors have suggested that the socioeconomic patterning of occupational sitting time may explain the unexpected health outcomes (Stamatakis et al., 2013, van der Ploeg et al., 2015, Pinto Pereira et al., 2012). Higher occupational sitting time is associated with higher income (De Cocker et al., 2014, Hadgraft et al., 2015, Stamatakis et al., 2014) and higher education (De Cocker et al., 2014). While the studies cited in this section controlled for indicators of socioeconomic position (e.g., education, employment grade, social class), it is possible that these covariates may not fully account for socioeconomic effects. Thus, it may be that occupational sitting is weakly associated with poor health outcomes because it is linked with high socioeconomic position. As with television time, further research is needed to explore these possible explanations.

2.4.3 Conclusion

Television time and occupational sitting time are two of the most commonly measured sedentary behaviours, largely due to their assumed modifiability and prevalence, respectively. While television time has been repeatedly linked to poor health outcomes, it is not clear why television time is so detrimental. Concurrent snacking, prolonged sitting, and low levels of muscular activation have been suggested explanations, although others have suggested that television time may be an indicator of social disadvantage. In contrast, occupational sitting time has not been demonstrated to have comparable ill effects on health despite the large volume of sedentary time it often contributes. It is similarly unclear whether the minimal effects of occupational sitting time are attributable to the nature of occupational sitting (e.g., if it is frequently interrupted or associated with higher levels of muscular activation), or whether the null effects of occupational sitting are confounded by high socioeconomic position.

2.5 Objectively measured sedentary time during pregnancy

The literature presented thus far has discussed the effects of sedentary time and sedentary behaviour in the general population. Relatively little work has been done to understand sedentary behaviour/time during pregnancy, especially among a 'high risk' group, who is the focus of this thesis. To this end, this section summarises the data available concerning objectively measured sedentary time during pregnancy regardless of 'risk' status, although details about the study samples are provided in the text to facilitate interpretation. This section aims to address: how

much time pregnant women spend sedentary, whether sedentary time during pregnancy differs from non-pregnancy, and what is known about the sociodemographic patterning of sedentary time during pregnancy.

2.5.1 How much time do pregnant women spend sedentary?

To date and to my knowledge, 13 studies[9] have reported data on objectively measured sedentary time during pregnancy, either reporting sedentary time and other accelerometry variables as the main outcomes of the study (DiFabio et al., 2015, Evenson and Wen, 2011, McParlin et al., 2010, Lof, 2011, Hawkins et al., 2017, Hayes et al., 2015) or testing associations between sedentary time during pregnancy and maternal or foetal outcomes (Hayes et al., 2014, Loprinzi et al., 2013, Nayak et al., 2016, Gradmark et al., 2011, Hawkins et al., 2014, Reid et al., 2014, Ruifrok et al., 2014). This section describes the findings of the former; the latter are discussed in section 2.7.

The highest-quality data available describing sedentary time during pregnancy come from a small study (n=46 healthy pregnant women, all of whom had at least some university education) by DiFabio et al. (2015) in the US in which participants wore an activPAL at two time points during pregnancy (second and third trimester). These data suggest that sedentary time accounted for 11.4 and 11.6 hours per day, which was 66.3% and 67.1% of waking hours[10] in the second and third trimester, respectively.

To date, the only population-based measurement of sedentary time during pregnancy also comes from the US. Evenson and Wen (2011) analysed cross-sectional 2003-6 NHANES data with women in all three trimesters included (n=359). They reported that mean sedentary time (measured by the waist-worn Actigraph) was 7.1 hours per day (57.1% of wear-time) and that it did not change across trimesters. However, the wear-time criteria for data sets to be considered valid were

[9] Four of these (Evenson and Wen (2011), Hawkins et al. (2017), Loprinzi et al. (2013), and Hawkins et al. (2014)) analysed different aspects of data from the 2003-6 NHANES cycle

[10] The activPAL data in the paper is sitting and lying time pooled together with nighttime sleep included. I manually calculated sedentary time during waking hours by subtracting nighttime sleep as measured by the SenseWear from the activPAL's sit+lie measurement.

very low (7.0 hours of weekdays and 5.6 hours on weekend days), which suggest their measurement of sedentary time in this sample may be an underestimation.

Finally, Hayes et al. (2015) and McParlin et al. (2010) measured sedentary time among overweight and obese pregnant women in the UK (separate samples) using the waist-worn Actigraph. In Hayes et al.'s (2015) sample (n=140 at first trimester), sedentary time accounted for 73%, 75%, and 74% of wear-time in the first, second, and third trimesters, respectively. This is generally consistent with McParlin et al.'s (2010) sample (n=55 at first trimester) in which sedentary time accounted for 80%, 81%, and 79% of waking hours in each trimester.

Notably, no studies to date have looked at the patterning of sedentary time during pregnancy to know which days of the week or which times of the day might have especially high or low sedentary time. Understanding daily and hourly patterning of sedentary time has been of recent interest in the general population (McVeigh et al., 2016, Bellettiere et al., 2015) to identify where relatively high periods of sedentary time tend to occur.

2.5.2 Comparison of sedentary time between pregnant and non-pregnant women

To my knowledge, two studies to date have compared the objectively measured sedentary time of women who were pregnant with women who were not. In Sweden, Lof (2011)'s data suggested that pregnant women at 32 weeks' gestation (n=18) have higher total sedentary time (measured via IDEEA[11]) than non-pregnant women (n=21)[12]. Using NHANES data, Hawkins et al. (2017) compared the sedentary time (Actigraph) of pregnant (n=234) and non-pregnant (n=1146) women and similarly reported that pregnant women (all trimesters cross-sectionally included) had higher total sedentary time than non-pregnant women. In that same sample, total sedentary time (both absolute and as a proportion of wear time) did not differ by trimester, although time spent in prolonged sitting bouts (lasting ≥15 minutes)

[11] The IDEEA is the Intelligent Device for Energy Expenditure and Activity, which is a multi-sensor accelerometer that has been validated for the measurement of sedentary time (Zhang et al. 2003)

[12] It should be noted that the pregnant and non-pregnant women in this sample were not matched for age (the pregnant women were younger) or parity (a smaller proportion of the pregnant women were nulliparous compared to the non-pregnant women)

increased linearly as pregnancy progressed (Hawkins et al., 2017). Thus, there is some evidence to suggest that sedentary time may be higher during pregnancy, especially later in pregnancy, although this evidence is limited by between-individual rather than within-individual design.

2.5.3 Predictors of objectively measured sedentary time during pregnancy

To my knowledge, two studies have examined whether sociodemographic characteristics are associated with objectively measured sedentary time during pregnancy. In the US, Evenson and Wen (2011) examined sociodemographic correlates of Actigraph-measured sedentary time during pregnancy, including age, gestational age, ethnicity, education, household income, marital status, smoking status, prior preterm delivery, and health insurance in a multivariate model. Their results indicated that only smoking was significant, such that those who reported any smoking in the last five days had lower sedentary time than those who did not report any smoking (Evenson and Wen, 2011). In the UK, McParlin et al. (2010) compared Actigraph-measured sedentary time in the first trimester between nulliparous and multiparous women and found no significant difference, suggesting that parity did not significantly impact sedentary time.

Thus, there is weak evidence describing the sociodemographic patterning of sedentary time during pregnancy. This has primarily been limited by the measure of sedentary time (Actigraph) and has not taken other potentially relevant factors such as employment status or neighbourhood deprivation into account.

2.5.4 Conclusion

Most of the results available to date have described the objectively measured sedentary time of women during pregnancy are affected by key methodological limitations, primarily the use of waist-worn devices that cannot differentiate sitting from standing, and short wear-time requirements which may significantly underestimate total sedentary time. Measurements of sedentary time that account for posture and the full 24-hour period are needed to deepen understanding of the prevalence and patterning of sedentary time during pregnancy. Furthermore, data on the sociodemographic correlates of sedentary time during pregnancy are very

limited but are necessary to understand how sedentary time might be distributed across the population.

2.6 Sedentary behaviours during pregnancy

There is currently little evidence about time spent in specific sedentary behaviours during pregnancy. As with the general population, the most commonly measured sedentary behaviour during pregnancy has been television time. In some cases, the prevalence of television time (and physical activity) has been the focus of the study (Evenson and Wen, 2010b, Pereira et al., 2007, Oviedo-Caro et al., 2018, Xu et al., 2018), while other studies have measured television in relation to pregnancy outcomes, usually glucose tolerance (Padmapriya et al., 2017, Oken et al., 2006, Gollenberg et al., 2010).

2.6.1 Television time during pregnancy

The majority of information about the prevalence of television time during pregnancy comes from the US, where the prevalence of those watching two or more hours of television in the sample population has been reported as 34% (Oken et al. (2006), n=1581, second trimester), 62% (Gollenberg et al. (2010), n=1231, Latinas in the US in mid-pregnancy), and 68% (Evenson and Wen (2010), n=638, 2003-6 NHANES data, all trimesters). In a Chinese sample (n=2345), 25.1% reported watching at least 2 hours of television per day during pregnancy (no specific referent period; Xu et al. (2018)), and 32.1% of a sample in Singapore (n=1083) reported watching at least 3 hours of television per day during the second trimester (Padmapriya et al., 2017). Mean daily television time among a small (n=186) sample in Spain was 2.3 hours per day among participants in their second and third trimesters (Oviedo-Caro et al., 2018), and in the US, mean self-reported television time per week in mid-pregnancy (n=1442) was 11 hours (Pereira et al., 2007). No studies to my knowledge have reported television time during pregnancy among women in the UK. Taken together, there is substantial variation in the proportion who have high television time across different samples in different geographical locations.

2.6.2 Other sedentary behaviours during pregnancy

Beyond television time, only two studies have explored time spent in other sedentary behaviours during pregnancy. Using 2003-6 NHANES data, Evenson and Wen (2010b) reported on both television time (mentioned in the previous paragraph) and non-occupational computer use, indicating that only 10.6% of participants used the computer for at least two hours per day (all trimesters). Oviedo-Caro et al. (2018) used the Sedentary Behaviour Questionnaire among women in their second and third trimesters in Spain and reported that the largest volume of sedentary time (2.3 hours per day) was accumulated watching television, followed by sitting to eat (1.8 hours per day), lying down or resting (1.7 hours per day), and using the computer (0.4 hours per day).

2.6.3 Predictors of sedentary behaviours during pregnancy

No studies have examined the sociodemographic predictors of sedentary behaviours (specifically television time and occupational sitting time) during pregnancy.

2.6.4 Conclusion

While television time is the most commonly measured sedentary behaviour during pregnancy, its prevalence during pregnancy among women in the UK is not known. The prevalence of occupational sitting time during pregnancy has also not been examined. Importantly, the sociodemographic patterning of these sedentary behaviours during pregnancy has not been explored.

2.7 Associations between sedentary time and sedentary behaviours during pregnancy and pregnancy outcomes

This section discusses the work that has tested associations between sedentary time and sedentary behaviour during pregnancy and pregnancy outcomes. As data concerning sedentary time and pregnancy outcomes are sparse, this discussion combines evidence based on both objective and subjective measures of sedentary time/behaviour. For simplicity, this discussion is organised by pregnancy outcome, but the measurement approach used by each study is specified within the text to facilitate interpretation.

2.7.1 Sedentary time/behaviour during pregnancy and glucose metabolism

2.7.1.1 Sedentary time/behaviour and incident gestational diabetes

To date, no studies have tested an association between objectively measured sedentary time and gestational diabetes incidence.

Three studies have tested an association between self-reported television time and gestational diabetes or abnormal glucose tolerance, and all three reported no associations. Padmapriya et al. (2017) reported no association between television time (dichotomised as less than or ≥3 hours per day, reported at 26-28 weeks' gestation) and gestational diabetes among 1083 women in Singapore in models that were both unadjusted (OR 0.82 (95%CI 0.58, 1.18)) and adjusted (OR 1.03 (95%CI 0.70, 1.51)) for factors including BMI, previous GDM, and family history of diabetes. Oken et al. (2006) reported no association between television time (dichotomised as less than or ≥2 hours per day, reported at 26-28 weeks' gestation) and gestational diabetes (OR 1.03 (95%CI 0.59, 1.78)) or abnormal glucose tolerance (OR 1.01 (95%CI 0.75, 1.35)) after adjustment for BMI, GDM history, family history of diabetes, and physical activity among 1805 women in the United States. Finally, Gollenberg et al. (2010) reported no association between television time (categorised as <1, 1 to <2, 2 to <4, ≥4 hours per day in early and mid-pregnancy) and abnormal glucose tolerance among 1231 Latinas in the United States (p for trend=0.61 and 0.42 for early and mid-pregnancy, respectively).

Other subjective measurements of sedentary time during pregnancy have had mixed associations with gestational diabetes and abnormal glucose tolerance. In the same study as mentioned above, Padmapriya et al. (2017) asked participants to report their total usual sitting time in a day; categories of total sitting time (<7 hours per day, 7-10 hours, and ≥10 hours per day) had no association with GDM (for highest versus lowest, OR 1.42 (95%CI 0.90, 2.22)). Leng et al. (2016) measured time spent 'sitting at home' (including television time, reading, using the computer, and other sitting such as meal time) during the second trimester among 11,450 women in China and reported that those who reported sitting at home for 2-4 hours a day and ≥4 hours per day each had a higher likelihood of developing GDM than those who sat at home for <2 hours per day, after adjustment for factors including BMI and family history of diabetes (OR 1.59 (95%CI 1.18, 2.15) and OR 1.73 (95%CI 1.22, 2.43),

respectively). Finally, Gollenberg et al. (2010) created a composite measure of television time plus time spent sitting at work (with exercise reverse-scored, which may be considered as a measure of physical inactivity) and reported that in mid-pregnancy this composite was associated with significantly higher likelihood of abnormal glucose tolerance (OR 11.8 (95%CI 2.25, 61.86)) among the same Latina sample as described above.

In summary, no studies to date have tested an association between objectively measured sedentary time and incident gestational diabetes. No studies to date have detected associations between television time and gestational diabetes or abnormal glucose development. Several studies have reported associations between composite measures of self-reported sedentary time and GDM or AGT, although the validity of these measurements is unclear.

2.7.1.2 Sedentary time and glucose levels

To date, four studies have tested associations between objectively measured sedentary time and indicators of glucose regulation (see Table 2.3 for details). Among obese women in the UK, Hayes et al. (2014) found no association between sedentary time (Actigraph) at 16-18 weeks' or 27-28 weeks' gestation and fasting or 2-hour glucose levels (n=63 and n=43 at each time point). Using data from the 2003-6 NHANES cycle, Loprinzi et al. (2013) reported no association between sedentary time (Actigraph) during pregnancy and fasting glucose (n=206). Among overweight and obese women in the Netherlands, Nayak et al. (2016) reported no association between sedentary time (Actigraph) and fasting glucose, fasting insulin, insulin sensitivity, or first- or second-phase insulin responses when repeated measurements were taken at 15, 24, and 32 weeks' gestation (n=46). Finally, Gradmark et al. (2011) compared the insulin responses of pregnant (n=35) and non-pregnant (n=69) women in Sweden; among the pregnant sub-sample (n=35), no association was found between sedentary time (Actiheart[13]) at 28-32 weeks' gestation and β-cell response or insulin sensitivity (nor was an association found among the non-pregnant subsample).

[13] The Actiheart is a chest-worn accelerometer that also measures heart rate; sedentary time in this study is measured as lack of movement with valid heart rate data (to differentiate from non-wear)

Two of the studies that tested self-reported sedentary time during pregnancy and GDM (as described in the previous section) also tested associations with glucose levels (Table 2.3). Padmapriya et al. (2017) reported no association between television time (dichotomised as less than or ≥3 hours per day) or total sitting time (<7 hours per day, 7-10 hours per day, ≥10 hours per day) reported at 26-28 weeks' gestation and fasting or 2-hour glucose levels. Gollenberg et al. (2010) reported that their measure of sedentary time (television plus sitting at work plus lack of physical activity) in mid-pregnancy was associated with 1-hour glucose levels (β=0.08, p=0.04), although it is unclear whether other variables were controlled in the model.

In summary, none of the four studies that objectively measured sedentary time reported an association between sedentary time during pregnancy (measured at various and sometimes repeated time points) and indicators of glucose regulation, including fasting glucose and insulin levels, 2-hour glucose levels, and markers of insulin sensitivity. However, none of these studies used devices that could detect posture, which is a key limitation in their measurement of sedentary time. Subjective measures of sedentary time have had mixed associations with glucose levels.

Table 2.3. Summary findings of studies examining associations between sedentary time or sedentary behaviour during pregnancy and glucose levels or insulin resistance (HOMA-IR)

Study	Sample	Sedentary time measurement	Gestational age at measurement of ST	Fasting glucose	2-hour glucose	HOMA-IR	Control variables
Hayes et al. (2014)	Obese women in the UK (UPBEAT pilot), n=183	Actigraph (waist-worn)		Correlation coefficient			None
			16+0 to 18+6 weeks	0.16 (NS)	0.10 (NS)		
			27+0 to 28+6 weeks	0.09 (NS)	0.13 (NS)		
Loprinzi et al. (2013)	Pregnant subsample from 2003-6 NHANES cycle (n=206)	Actigraph (waist-worn)		β (95%CI)			Age, smoking, **education**, marital status, **poverty-to-income ratio**, ethnicity, gestational age, **BMI, MVPA**
			All trimesters included together	0.02 (-0.001, 0.04), p=0.06			
Nayak et al. (2016)	Obese Dutch women (recruitment details not provided), n=46	Actigraph (waist-worn)		β (95%CI)			Age, **BMI, MVPA**
			15 weeks	0.01 (-0.01,0.03)	-0.18 (-1.70, 1.34)	-0.02 (-0.36, 0.32)	
			24 weeks	-0.01 (-0.04, 0.01)	-0.27 (-1.85, 1.31)	-0.11 (-0.52, 0.30)	
			32 weeks	-0.01 (-0.05, 0.03)	-1.64 (-4.40, 1.12)	-0.44 (-1.09, 0.22)	
Padmapriya et al. (2017)	Pregnant women in Singapore (Chinese, Malay, or Indian ethnicity), n=1083	Questionnaire: total sitting time per day (collapsed to <7, 7-10, ≥10 hours per day), television time per day (dichotomized as < or ≥3 hours per day)		β (95%CI)			Age, ethnicity, **education**, **BMI**, parity, history of GDM, family history of diabetes, dietary energy intake, smoking, pregnancy weight gain
			26-28 weeks' gestation, with the entire pregnancy as the referent period				
			Total sitting (7-10 vs <7 hours)	0.04 (-0.04, 0.13)	0.23 (-0.02, 0.47)		
			Total sitting (≥10 hours vs <7 hours)	-0.04 (-0.12, 0.04)	0.17 (-0.06, 0.40)		
			TV time (≥3 vs <3 hours)	0.03 (-0.04, 0.10)	0.05 (-0.15, 0.25)		
Gollenberg et al. (2010)	Latina women in the US (n=1231)	Questionnaire: television time plus work sitting with exercise reversed scored			β (no CI provided)		None listed
			24-28 weeks		0.08, p=0.04 (1-hour GTT)		

2.7.2 Sedentary time/behaviour during pregnancy and blood pressure regulation

2.7.2.1 Objectively measured sedentary time and blood pressure

To my knowledge, only one study has examined the association between objectively measured sedentary time during pregnancy and blood pressure. Loprinzi et al. (2013) analysed the pregnant subset of the 2003-6 NHANES data set and reported that sedentary time (Actigraph, n=206, participants were from all three trimesters) was not associated with systolic (β=-0.004 (95%CI -0.01, 0.007)) or diastolic blood pressure (β=0.002 (95%CI -0.02, 0.03)) in multivariate analyses that controlled for MVPA, BMI, and other relevant covariates.

2.7.2.2 Subjectively measured sedentary time and blood pressure

Chasan-Taber et al. (2015) used the Pregnancy Physical Activity Questionnaire to classify respondents (n=1240 Hispanic women in the United States) by tertile of sedentary time (based on the sum of self-reported television time, sitting at home, sitting at work, and sitting during transportation). Tertile of sedentary time was not associated with likelihood of developing gestational hypertension during pregnancy after controlling for age, BMI, and parity (p=0.86) (Chasan-Taber et al., 2015).

2.7.3 Sedentary time/behaviour during pregnancy and gestational age at delivery

2.7.3.1 Objectively measured sedentary time

Ruifrok et al. (2014) reported that sedentary time (Actigraph) during pregnancy (at 15 weeks' and 32-35 weeks' gestation) was not associated with gestational age at delivery in a sample of Dutch women (n=111), although the data were not shown so the effect size is unknown.

2.7.3.2 Subjectively measured sedentary time

To my knowledge, no subjective measurements of sedentary time have been used to test an association with gestational age at delivery.

2.7.4 Sedentary time/behaviour during pregnancy, birthweight, and macrosomia

2.7.4.1 Objectively measured sedentary time

Ruifrok et al. (2014) reported no association between sedentary time (Actigraph) at 15 weeks' gestation and birthweight among 111 Dutch women (β=2.45 (95%CI -5.5, 10.4)). Similarly, the change in sedentary time from 15 to 32-35 weeks' gestation was not associated with birthweight (β=0.59 (95%CI -8.9, 10.1)).

In the UK, Reid et al. (2014) compared the sedentary time (Sensewear) of women who were not predicted to deliver macrosomic babies (n=50) with women who were predicted to deliver macrosomic babies (n=50) based on ultrasound scans between 29-35 weeks' gestation (macrosomia defined as ≥4000g). They reported that women who were predicted to deliver macrosomic babies had higher sedentary time in the third trimester than women who were not predicted to deliver macrosomic babies (adjusted difference in means 2.0 hours per day (95%CI 0.3, 3.7)) after adjustment for age, parity, smoking, and education (but not BMI). However, the case-control design of this study precludes interpretations of causality.

Also in the UK, Hayes et al. (2014) reported that sedentary time at 16-18 weeks, 28 weeks, and 36 weeks' gestation was not significantly different between those who delivered macrosomic (≥4000g) babies (n=26) and those who did not (n=114) ($p>0.05$ at all time points).

2.7.4.2 Subjectively measured sedentary time

Badon et al. (2018) tested an association between self-reported sedentary time (time spent watching television and sitting quietly and performing an activity 'such as reading or knitting') at 15 weeks' gestation and birthweight among 1535 women in the United States. They reported no association between quartile of sedentary time and birthweight after adjustment for a number of covariates including BMI, gestational age at delivery, and leisure-time MVPA (p for trend=0.64).

2.7.5 Sedentary time during pregnancy and other cardio-metabolic biomarkers

Based on data from the 2003-6 NHANES cycle, Loprinzi et al. (2013) reported that sedentary time during pregnancy (Actigraph) was positively associated with C-

reactive protein (β=0.001 (95%CI 0.0001, 0.003)) and LDL-cholesterol (β=0.12 (95%CI 0.02, 0.22)) among pregnant women in the US in all three trimesters (n=206) after adjustment for BMI, MVPA, and other covariates. No associations with HDL cholesterol, total cholesterol, or triglycerides were found.

Using the same data set with a larger sample size (due to different inclusion criteria), Hawkins et al. (2014) reported that sedentary time was not associated with C-reactive protein (β=0.03, p=0.08) after adjustment for BMI, age, and other covariates (but did not control for MVPA).

2.7.6 Conclusion

To date, there are no data on objectively measured sedentary time and development of gestational diabetes, which is an important gap in knowledge to fill. The associations between self-reported sedentary behaviour/time and gestational diabetes or abnormal glucose tolerance are mixed, which may be due to the variation and unclear validity of the methods. The association between objectively measured sedentary time and glucose levels during pregnancy has been tested with no associations reported; however, each of these studies had substantial limitations in the measurement of sedentary time. Evidence for associations between sedentary time during pregnancy and other outcomes (blood pressure, gestational age, birthweight, macrosomia) has been weak and similarly limited by the measurements of sedentary time and the study design. Thus, associations between sedentary time and these outcomes need to be retested with higher-quality measurements of sedentary time and prospective study designs to clarify the possible effects.

2.8 Consideration of sedentary behaviours as social practices

Throughout this thesis thus far, the term *sedentary behaviour* has been used for the sake of consistency with the conventions of the broader field. However, Cohn (2014) has suggested that the use of the term *behaviour* is problematic for a number of reasons. At minimum, the term *behaviour* conceptually reduces health-related activities to products of individual choice, intention, and motivation, implying that what people do in everyday life is simply a matter of decision-making. This not only implies assumptions about morality and personal responsibility (i.e., implying that the 'healthy choices' are the individual's to make), but also strips away the complex social, political, and economic contexts within which people and their daily activities

are situated (Cohn, 2014). Thus, Cohn (2014) suggested a theoretical and practical shift away from focusing on health *behaviours* toward focusing on health *practices*.

Citing theoretical developments put forth by Shove et al. (2012), Blue et al. (2016) expanded upon Cohn's (2014) critique by drawing upon social practice theory as a way of understanding health practices as social practices. Social practices involve 'the active integration of generic *elements*, including materials/tools/infrastructures, symbolic meanings, and forms of competence and practical know-how' (Blue et al. 2016, p.41) and place the focus on the practice itself rather than on the individual 'doing' the practice. While Blue et al. (2016) illustrated how materials, competence, and meanings interact and underlie the practice of tobacco smoking as an example, the authors emphasised the applicability of this approach for understanding a wide range of health practices, including physical activity. To my knowledge, only one paper has considered sedentary behaviour as a social practice (among older adults) (Palmer et al., 2018). The following subsections argue that sedentary behaviour can (and should) be considered as a social practice by exploring its associated materials, competence, and meanings, drawing upon Palmer et al.'s (2018) recent work and other relevant literature. It should be noted that, despite this section's argument that *sedentary behaviours* should be considered as *sedentary practices*, the term *sedentary behaviour* is used throughout this section in the same way that it has been used throughout this thesis for the sake of consistency.

2.8.1 Materials

The materials of a social practice encompass the requisite 'objects, infrastructures, tools, hardware and the body itself' (Shove et al. 2012, p. 23). The materials associated with sedentary behaviour (sitting in particular) are widespread in the everyday environment – seats are available or built-in to workplaces (chairs at desks, conference rooms with tables and chairs), homes (sofas, kitchen tables with chairs), transport modes (seats in cars, buses, trains), entertainment venues (seats within auditoriums, theatres, and cinemas), and in the intermediate spaces in between (chairs in waiting rooms, benches at bus stops and train platforms). Indeed, it is the ubiquity of these material facilitators of sedentary behaviour that is often implicated as the primary reason that sedentary time has increased over the past half century (e.g., (Owen et al., 2010)). The body is another material component of sedentary behaviour; for example, one may need to sit to alleviate physical discomforts such as

back pain, and conversely, one may find that prolonged sitting may cause feelings of stiffness or discomfort (Palmer et al., 2018).

2.8.2 Competence

The competence or practical know-how associated with sedentary time is less clear, as knowing how to sit seems obvious. It is worth pointing out, however, that in many cases, sitting is not done for the sake of sitting but is the requisite posture for doing something else. In that sense, competence may refer to knowing how to, for example, read a book, work the television, or use the computer. Competence may also tie into knowing when one needs to sit, for example in response to feeling tiredness or soreness in the body, thus overlapping with the material element of the body.

2.8.3 Meanings

Finally, and arguably most importantly, the meaning that represents the 'social and symbolic significance of participation' (Shove et al. 2012, p. 23) associated with sedentary behaviour is often overlooked. For example, sitting has meanings associated with hospitality (e.g., inviting one in to sit), equality (i.e., being at eye-level with others), and self-care (e.g., sitting down to rest). The social meanings and implications of sitting clearly emerge within qualitative studies of participants' experiences or thoughts about prospective or past interventions aimed at reducing sitting time. For example, in an office-based workplace intervention aimed at reducing sitting time by encouraging employees to get up from their desk more frequently, the association of sitting with productivity and commitment emerged as employees expressed concerns that standing or moving around at work may make them perceived as taking their jobs less seriously (De Cocker et al., 2015, Niven and Hu, 2018, Mackenzie et al., 2018). In an experimental intervention in which participants (university employees) were asked to stand in meetings that were traditionally seated (not all meeting attendees took part in the intervention), participants described the social discomfort that they felt during the meeting; they felt like they were not a part of the group and that they were challenging the authority of the meeting convenor because they were standing (Mansfield et al., 2018). These statements suggest sitting might carry meanings of cohesion (if everyone is seated together) as well as subservience and power dynamics, and these

meanings are disrupted when a seated posture is expected, but not adopted. Similar qualitative approaches have been applied to understand sedentary behaviour in non-workplace contexts, either based on participants' experiences of an intervention (Greenwood-Hickman et al., 2016) or based on participants' accounts of how sedentary behaviour fits within their lives to inform the development of future interventions (Deliens et al., 2015, Palmer et al., 2018, McEwan et al., 2017). Participants' quotations within these studies have suggested that taking part in seated activities such as watching television had meanings of relaxation and reward at the end of the day (Greenwood-Hickman et al., 2016, Deliens et al., 2015, Palmer et al., 2018). Activities such as sitting to socialise or do other recreational pursuits such as knitting were seen as important, valuable parts of their lives (McEwan et al., 2017, Palmer et al., 2018). Thus, sedentary behaviours are deeply embedded into daily routines, and the meanings attached to the activities that take place while sitting (of productivity, pleasure, relaxation, value) are not often taken into account when understanding *why* people might sit, which has important implications for any interventions aimed at the reduction of sitting time (Palmer et al., 2018).

2.8.4 Conclusion

This section has illustrated examples of the materials, competence, and meanings that may underlie sedentary behaviour, arguing that sedentary behaviour is best considered as a social practice, which may be important for two main reasons. First, interventions to reduce sedentary time are often unsuccessful, particularly in the long-term (Shrestha et al., 2018a), perhaps due (at least in part) to their focus on changing the 'material' component of sedentary time (i.e., by providing standing desks in the workplace) without consideration for the associated 'meanings.' Second, consideration of sedentary behaviour as a social practice provides a framework for understanding ways in which sedentary practices might vary across adult populations. More specifically, while sedentary time/behaviour is universally embedded in everyday lives, the materials, competence, and meaning that underlie sedentary practices may be variable and nuanced across different subgroups within a population – including during pregnancy. This is discussed further in the following section.

2.9 The impact of pregnancy on sedentary practices

In this section, the specific ways in which the elements (materials, competence, meanings) of sedentary practices might be unique during pregnancy are explored and discussed. It should be noted that while this discussion is focused on *sedentary* practices, the dearth of literature concerning sedentary time/behaviour during pregnancy necessitates the inclusion of literature focused on *physical activity* during pregnancy. While it is acknowledged that sedentary behaviour and physical activity are not necessarily interchangeable, considering them together may offer a complementary understanding how of pregnancy may alter sedentary/activity practices as a whole.

The materials associated with sedentary practices during pregnancy are likely to resemble the materials described above (places to sit, physical symptoms), with some key differences. There are more spaces for women to sit down during their pregnancies in the everyday environment; for example, many modes of public transportation and other public spaces have priority seats specifically intended for pregnant women (or others who may have difficulty standing). This is interlinked with the other key material change during pregnancy: physical changes and associated limitations. The physical experiences of pregnancy have played a well-documented role in physical activity reduction during pregnancy; for example, tiredness, nausea, back pain, pelvic girdle pain, and other physical discomforts have been reported as inhibitors of physical activity during pregnancy (Weir et al., 2010, Padmanabhan et al., 2015, Leiferman et al., 2011, Cramp and Bray, 2009, Jelsma et al., 2016, Cioffi et al., 2010, Connelly et al., 2015, Denison et al., 2015, Flannery et al., 2018, Evenson et al., 2009, Leppanen et al., 2014, Bauer et al., 2018, Haakstad et al., 2018). It is possible that, by extension, these physical symptoms of pregnancy may also serve as a facilitator of sedentary time.

The competence associated with physical activity practices during pregnancy may manifest as 'knowing how' to go about physical activity during pregnancy and how gauge the appropriate intensity and duration (i.e., 'knowing when' to stop and/or rest). Indeed, uncertainty and confusion about what physical activities are 'safe' and 'appropriate' during pregnancy have been identified as common reasons that many women avoid or reduce physical activity during pregnancy (Weir et al., 2010, Padmanabhan et al., 2015, Leiferman et al., 2011, Cioffi et al., 2010, Connelly et al.,

2015, Denison et al., 2015, Flannery et al., 2018, Haakstad et al., 2018). This uncertainty is understandable given the way in which government-issued pregnancy guidance and guidelines emphasise the importance of 'not overdoing it' alongside a long list of activities to avoid (skiing, surfing, off-road cycling, gymnastics, horseback riding, contact sports, scuba diving, activities lying flat on the back, and higher-intensity activities such as running, jogging, racquet sports, and strenuous strength training for women who were not already active prior to pregnancy) (National Health Service, 2009, Department of Health and Social Care, 2017, American College of Obstetrics and Gynecology, 2015). Beyond having to 'know' what physical activities and intensities are 'safe' during pregnancy, women are advised by health care professionals to 'know' their bodies' limits to identify appropriate physical activity durations and intensities and to know when to stop (Ferrari et al., 2013, Department of Health and Social Care, 2017, Evenson et al., 2009). Thus, physical activity during pregnancy requires special competence surrounding knowing what physical activity is 'safe' and 'appropriate', as well as knowing how to assess the limitations of one's own body.

Arguably, the most substantial way in which physical activity (and sedentary time) as social practices may differ during pregnancy is in its meaning. A quantitative, questionnaire-based finding reported by Clarke and Gross (2004) indicated that pregnant women in the UK considered it more important to get sufficient rest than to be active during their pregnancies. As the study was quantitative, the authors could only offer statistical suggestions as to why rest may have been perceived as more important than physical activity during pregnancy. This compelling finding (and curiosity as to what this result might mean) was the impetus for exploring the social context of sedentary time ('resting') in this study. While an in-depth theoretical explanation concerning why physical activity and sedentary time may have unique meanings during pregnancy is beyond the scope of this thesis, failing to discuss concepts that may underlie this special meaning within an anthropological thesis would be a glaring omission. To this end, two tightly interrelated ideas that may be directly relevant to the unique construction of the meaning and social context of physical activity and sedentary time during pregnancy are discussed in the following sections, although it is acknowledged that these merely scratch the surface of possibilities.

2.9.1 Maternal responsibility for the vulnerable foetus

Among studies aiming to understand physical activity engagement during pregnancy (including reasons for non-engagement) using both qualitative and quantitative methods, one of the most common reasons women gave for ceasing or avoiding physical activity during pregnancy is concern about its safety for the foetus (Cioffi et al., 2010, Connelly et al., 2015, Denison et al., 2015, Weir et al., 2010, Padmanabhan et al., 2015, Leiferman et al., 2011, Haakstad et al., 2018). While the same respondents report knowing that physical activity is beneficial for the maternal body, citing benefits such as easier labour (Cioffi et al., 2010, Denison et al., 2015, Leiferman et al., 2011, Weir et al., 2010), improved physical symptoms (Denison et al., 2015), improved mood and mental wellbeing (Cioffi et al., 2010, Denison et al., 2015, Weir et al., 2010, Leiferman et al., 2011, Duncombe et al., 2009), and weight management (Cioffi et al., 2010, Denison et al., 2015, Weir et al., 2010, Leiferman et al., 2011, Duncombe et al., 2009), the uncertainty surrounding what is safest for the foetus prevails. Thus, negotiating physical activity practices during pregnancy requires negotiating conflict between what is perceived to be 'good' for the foetus and 'good' for the maternal body, although the complexity of this negotiation is absent from the physical activity literature.

In contemporary 'Western' culture, pregnancy is understood, experienced, and monitored in terms of potential risk to the foetus (Lupton, 2012, Holland et al., 2016). While the social construction and representation of the foetus has varied across cultural and historical contexts, the foetus has long been perceived as vulnerable (Lupton, 1999, Han, 2018). This is evident in Gelis' (1991) description of the history of pregnancy and childbirth practices in early modern Europe:

> *'Indeed it was customary for women to remain as inactive as possible during early pregnancy, when the foetus's hold on life was so fragile. In any case, observation of nature confirmed the idea: a fruit is never in greater peril than when it is forming or when the tree is in flower; a sharp shower of rain, a late frost, an ill-timed shaking of the trunk, and the hopes of a whole year can be endangered in a few minutes'* (p. 77).

The antenatal focus on the 'vulnerable' foetus intensified toward the end of the twentieth century as developments in biomedical technology, particularly the

ultrasound scan, contributed to the social construction of the foetus as a *person* with an identity that is separate from the mother (Oakley, 1984, Han, 2018, Lupton, 1999). The use of these technologies has contributed to the construction of the foetus as ''the patient,' seen to have its own rights, which may differ from or conflict with those of its mother' (Lupton, 2012, p. 335).

Despite the construction of the foetal identity as separate from the maternal body, the actions of the mother are assumed to directly impact the foetus. Pregnant women are held fully responsible and personally accountable for the health and development of the foetus (Harper and Rail, 2012, McNaughton, 2011, Lupton, 1999, Bell et al., 2009). Even in the case of foetal abnormalities or developmental problems, which can be caused by a wide variety of complex factors, the blame may be directed toward the mothers (Lupton, 2012, Lupton, 1999, Harper and Rail, 2012). This projection of responsibility onto mothers is also a theme that frequently emerges within biomedical and academic contexts. For example, the Developmental Origins of Health and Disease (DOHaD) research paradigm posits that foetuses' metabolic and developmental health are 'programmed' in utero (Barker, 2012), a finding taken to indicate that the actions and physical status of the mother have the power to determine the wellbeing of the offspring for life. The obesity and 'diabesity' discourses project the same message, implicating obese or diabetic pregnant women as primarily responsible for perpetuating the 'cycle' in which 'diabetes begets diabetes' (Zhang et al., 2014, McNaughton, 2011, Warin et al., 2011).

2.9.2 Good mothers avoid posing any 'risks'

Given the maternal responsibility to protect the vulnerable foetus, the practices of women during their pregnancies (and indeed for their entire mothering careers) are appraised as either 'good' or 'bad' in expert, policy, and public discourse (Lee, 2008). What constitutes the classifications of 'good' or 'bad' mothering practices is culturally and temporally specific (McNaughton, 2011), but at least within modern 'Western' contexts, 'good mothering' is linked to avoiding anything that may pose a risk to the foetus (Lee, 2008, Burton-Jeangros, 2011), both through the alteration of her behaviours and actions (Lupton, 2012, Jette and Rail, 2014) and through heeding 'expert' medical advice (Lupton, 1999). However, the specific behaviours and actions considered to pose a 'risk' to the foetus (and thereby what 'good mothers' 'should' do) are variably defined, and may be based on complex and ongoing interpretations

and negotiations of information gleaned from biomedical knowledge, social norms, and lived experiences (Root and Browner, 2001, Holland et al., 2016, Alaszewski, 2005). Thus, what is deemed 'risky' to a foetus (and thus grounds for social disapproval of 'bad mothering') may be complexly contingent on the particular perception of risk in a given social context.

Despite no evidence to suggest that physical activity during pregnancy is harmful to the foetus, activity during pregnancy is broadly publicly perceived to potentially put the foetus 'at risk' (van Mulken et al., 2016). This perception may be linked to the tendency of biomedical information/advice to discuss physical activity during pregnancy in vague terms or with a long list of caveats and limitations (Root and Browner, 2001, Stengel et al., 2012, Padmanabhan et al., 2015, Clarke and Gross, 2004), the 'social norm' for women to reduce their activity during pregnancy (van Mulken et al., 2016), and/or women's lived or shared experiences of poor foetal outcomes which they have linked to 'too much' physical activity during pregnancy (Evenson et al., 2009). Thus, physical activity during pregnancy may be socially perceived as 'bad mothering' because of its suspected possible 'risk' to the foetus; unsurprisingly, physical activity during pregnancy is often not socially approved (Weir et al., 2010, Leiferman et al., 2011, Cioffi et al., 2010, Denison et al., 2015, Flannery et al., 2018, Evenson et al., 2009, van Mulken et al., 2016).

2.9.3 Conclusion

Physical activity and sedentary behaviour can both be considered social practices. The way in which physical activity and sedentary behaviour during pregnancy seem to be perceived differently compared to during non-pregnancy (as evidenced by uncertainty on the part of women and disapproval on the part of the public) suggest that physical activity and sedentary behaviour may have unique meanings during pregnancy. This section suggested that this difference in meaning may be attributable to perceptions linked to the 'vulnerable foetus' and the maternal responsibility to protect it from any risks, although more explanations than this are likely to exist. This highlights the importance of considering social context when examining physical activity and sedentary practices, especially during pregnancy, which to date have generally been overlooked.

2.10 Negotiating physical activity with an 'at-risk' pregnancy

A secondary aim of this thesis is to examine how participants in this study interpret what it means to be 'at risk' for gestational diabetes, and whether this status of being 'at risk' has any influence on physical activity practices.

To my knowledge, while a number of studies have explored how women respond to a *diagnosis* of gestational diabetes (e.g., (Evans and O'Brien, 2005, Parsons et al., 2014, Draffin et al., 2016, Jarvie, 2017)), only two studies have addressed pregnant women's responses to being told they are at risk for gestational diabetes. Ethnographic evidence among Pima women in the United States indicate that they conceptualised being 'at risk' for diabetes (both GDM and type 2) as being 'borderline' diabetic, but the high prevalence of diabetes among the Pima community seemed to make it inevitable (i.e., not preventable through physical activity) (Smith-Morris, 2005). The other study, based in Australia, used questionnaires to assess how women who were at risk for GDM (n=97) based on the same risk criteria as the sample is this study (BMI≥30, family history of type 2 diabetes, previous GDM, high-risk ethnicity group) perceived their risk; they reported that 50% of respondents did not believe they were at risk of developing GDM, and an additional 33% thought their risk was slight (16% of this cohort was diagnosed with GDM) (Harrison et al., 2012).

Understanding how being at risk for gestational diabetes is conceptualised and whether it has any impact on physical activity practices during pregnancy is of particular interest. Obesity, which is one of the most common risk factors for gestational diabetes in the UK, may have interesting implications for the 'meaning' of physical activity during pregnancy. For example, while a key concern about physical activity during pregnancy in general is possible impact on foetal wellbeing (see previous section), the impact of obesity on foetal development and wellbeing is also a concern during pregnancy, evidenced by increased medical surveillance of the foetuses of obese women (Furber and McGowan, 2011, Smith and Lavender, 2011). To this end, physical activity seems to be particularly encouraged for obese pregnant women by health care practitioners (McParlin et al., 2017), often in the interest of weight management (National Institute for Health and Care Excellence, 2008, Duthie et al., 2013). How these concerns of the impacts of obesity and physical activity

might intersect and contribute to the negotiation of physical activity practices during pregnancy is unclear.

2.11 Study aims and hypotheses

This thesis aims to build on the work that has been cited in this literature review and to fill in the key gaps in knowledge that have been identified. To this end, this thesis uses mixed methods to address the following aims and hypotheses:

1. To test associations between sedentary time and sedentary behaviours and gestational diabetes and glucose levels among women with a risk factor for GDM. Within this aim, the following specific hypotheses are tested:
    a. Total sedentary time will be positively associated with GDM and glucose levels
    b. Prolonged sedentary time will be positively associated with GDM and glucose levels
    c. Breaks in sedentary time will be negatively associated with GDM and glucose levels
    d. Sedentary time within compositional models will have no association with GDM or glucose levels
    e. Television time will be associated with GDM and glucose levels, and this effect will be larger than the effect of total sedentary time
    f. Occupational sitting time will have no association with GDM or glucose levels
2. To ascertain whether sedentary time is associated with other pregnancy outcomes that have been tested using lower-quality measurements of sedentary time, including systolic and diastolic blood pressure, gestational age at delivery, birthweight, and macrosomia.
3. To measure the total daily amount of time women spend sedentary and active during pregnancy, specifically during the second trimester, and to assess how sedentary time is diurnally and socially patterned.
4. To explore the social context of physical activity and sedentary time during pregnancy.
5. To examine how women with a risk factor for gestational diabetes interpret what it means to be 'at-risk' and to ascertain whether this risk status influences physical activity and/or sedentary time during pregnancy.

Chapter Three: Methodological literature review

Chapter Three explores the objective and subjective methodologies currently available to measure sedentary time, sedentary behaviour, and physical activity in adults, with a specific focus on methods validated for use during pregnancy where applicable. Each methodology is described and the practical considerations of each method are discussed. The most appropriate methods to measure sedentary time and physical activity in pregnant women are identified, and methodological decisions for data processing are evaluated.

3.1 Introduction

The primary aim of this study requires a valid and reliable measurement of the sedentary time of pregnant women. Simultaneously, this study aims to control for physical activity to assess the independent effect that sedentary time might have on the outcome variables. Thus, the methodological aims of this study prioritise the collection of high-quality, detailed data on sedentary time, with a secondary focus on the collection of physical activity data. To this end, this chapter's discussion of methodological decisions focuses on the measurement of sedentary time, with a secondary consideration of assessing physical activity.

This study will employ both objective and subjective measures. The purpose of the objective measures is to capture high-resolution, cross-sectional data on total sedentary time, which is necessary since self-reported measure of sedentary time are particularly prone to error (Atkin et al., 2012). The purpose of the subjective measures is to provide contextual information to determine how much sedentary time might be accumulated while watching television or sitting at work.

3.2 Criteria for evaluating methodological options

This section details methodological assessment criteria upon which candidate objective and subjective methods will be evaluated, to determine the most appropriate tools for use in this study.

3.2.1 Validity, sensitivity, and specificity

When assessing methodological options, it is essential that the device accurately measures the variable of interest, and that it does so consistently. The validity of a given device describes the extent to which the tool actually measures what it purports to measure (Tudor-Locke, 2016). This can be further broken down into sensitivity, which describes the device's ability to detect the occurrence of interest ('true positives'), and specificity, which describes the device's ability to exclude extraneous occurrences ('false negatives').

Criterion validity, sensitivity, and specificity can be assessed by comparing the measurements of a given device to a 'gold standard' measurement. In relation to the validity of devices for the objective measurement of sedentary time, the measurements of devices are often compared to direct observation. A device is considered to be a valid tool for the measurement of sedentary time or physical activity when the device's measurements are highly correlated ($r \geq 0.90$) with the criterion measurements (Chau et al., 2011, Kozey-Keadle et al., 2011, Lyden et al., 2012). Furthermore, tools with sensitivity ≥0.90 and specificity ≥0.90 are generally considered to have acceptable sensitivity and specificity (Steeves et al., 2015, Atkin et al., 2012, Pivarnik et al., 2016, Kim et al., 2015a).

3.2.2 Reliability

In addition to validity, a measurement tool's reliability, which describes the consistency of the measurement, must also be considered. Reliability is usually measured based on the agreement (intra-class correlation, ICC) of two measures taken by the same device. Although there are different types of reliability, test-retest reliability, which refers to the consistency of a tool's repeated measurements at two points in time (Tudor-Locke, 2016), is of particular relevance to this study because it is routinely assessed when subjective measurements are validated. Tools with an ICC of ≥ 0.80 are usually regarded as having acceptable reliability (Dahlgren et al., 2010, van Nassau et al., 2015, Rosenberg et al., 2010).

3.3 Objective measures for the measurement of sedentary time

Sedentary time is defined by three components – low energy expenditure (≤1.5 metabolic equivalents[14] (METs)) in a sitting/reclining posture during waking hours – and each of these components must be accounted for in order to get the most accurate measurements possible.

In free-living studies, the energetic component of sedentary time is rarely directly measured because such methodologies (e.g., indirect calorimetry) are impractical to deploy in such contexts due to the intrusiveness of the device (usually worn as a mask that covers the nose and mouth to capture gases), relatively short battery life, and high expense per unit. Thus, in free-living population studies, the energetic component of sedentary behaviour must be inferred through other measures. For example, accelerometers infer low energetic expenditure based on lack of movement, such that little-to-no movement is associated with low energetic expenditure, and higher intensity movements relate to higher energetic expenditure.

In addition to the measurement (or inference) of low energetic expenditure, devices must be able to detect posture in order to accurately distinguish whether the individual is truly sedentary (i.e., sitting or lying down) or is very lightly active (i.e., quietly standing) in periods of little-to-no movement. Devices worn around the waist (e.g., waist-worn ActiGraph), on the wrist (e.g., wrist-worn Actigraph), or on the arm (e.g., SenseWear armband) are unable to detect sedentary posture with high precision because, from those attachment points, standing and sitting are indistinguishable (van Nassau et al., 2015, Edwardson et al., 2016a, Reece et al., 2015, Hildebrand et al., 2017, An et al., 2017). Devices that are worn on the thigh seem to be best for determining posture because they can account for the orientation and movement of the thigh. To date, two devices have been validated for the detection of sedentary time due to their ability to determine posture: the thigh-worn Actigraph and the activPAL. These devices are discussed in turn below.

[14] A metabolic equivalent (MET) is defined as the ratio of energy expended through physical activity to basal metabolic rate. Thus a MET of less than 1.5 characterises very light activity such as using a computer, writing, driving, etc. This contrasts with activities done in a sitting posture with a high metabolic equivalent, such as cycling (5 to 10 METs, depending on intensity) which, although done in a sitting posture, is not considered sedentary.

3.3.1 Actigraph

3.3.1.1 Sedentary time measurement details

To date, the most common protocol for measuring sedentary time using the Actigraph has been using a waist-worn attachment site, although attaching the Actigraph at the wrist is gaining popularity (including in large-scale studies such as recent NHANES cycles) because of increased participant compliance (Troiano et al., 2014). In both the waist and wrist configurations, sedentary time is defined as non-movement. On the waist, sedentary time is most often defined as fewer than 100 counts per minute (Matthews, 2008, Healy et al., 2008a, Healy et al., 2011a, Hagstromer et al., 2007, Evenson and Wen, 2011). Evidence for the Actigraph's low validity for the measurement of sedentary time in the waist- and wrist-worn configurations can be found in Appendix 1.

The only way in which the Actigraph can identify posture is if it worn on the thigh. This configuration is able to identify posture using a proprietary algorithm designed for the thigh-worn configuration (inclinometer) that accounts for the accelerometry counts in the x, y, and z vectors to identify posture (sitting or standing) and movement (stepping).

3.3.1.2 Evidence of validation for the measurement of sedentary time

Three laboratory studies have validated the Actigraph worn on the thigh for the measurement of sedentary time (Edwardson et al., 2016a, Steeves et al., 2015, Pivarnik et al., 2016); two of these are summarised in Table 3.1. All three studies used direct observation as the criterion measure as participants engaged in various lying postures (e.g., lying on back, lying on the side), seated postures (e.g., sitting on a chair with feet flat on floor, sitting on chair with legs crossed), seated activities (e.g., reading), and upright activities (e.g., standing still, walking slowly, sweeping). Agreement between the thigh-worn Actigraph's postural classification of sedentary time and direct observation was ≥95% in almost all conditions (Edwardson et al., 2016a, Steeves et al., 2015, Pivarnik et al., 2016). The device was less accurate in correctly classifying lying on the back with knees bent (correctly classified 73% of the time; Edwardson et al., 2016a) and sitting on a 70-cm laboratory stool (correctly classified 85.7% of the time; Steeves et al., 2015). Thus, in some cases, sitting is misclassified (presumably as standing) if the thigh is not parallel to the ground even

though the subject is seated. It is important to note that the thigh-worn configuration of the Actigraph has only been validated for the measurement of sedentary time within laboratory settings (Edwardson et al., 2016a, Steeves et al., 2015); it has yet to be implemented in free-living studies. Furthermore, only its measurement of total sedentary time has been validated; whether the thigh-worn Actigraph can detect breaks in sedentary time is not known.

3.3.1.3 Practicalities of wear

The practicalities of wearing a device must also be taken into consideration in the process of selecting an accelerometer to use to maximise the likelihood of participant compliance. One of the primary drawbacks of the Actigraph (regardless of wear location) is that it is not waterproof, and in waist-wear configurations is usually removed at night-time (waking wear protocol) because it is uncomfortable to wear while sleeping. Thus, the wearer must remember to put the device back on, whether upon waking or after water exposure, which is likely to reduce compliance and increase the likelihood of insufficient hours of recorded data compared to a continuous wear protocol (Tudor-Locke et al., 2015, Pollard and Guell, 2012).

Because the Actigraph is designed to be worn around the waist or the wrist on an elastic belt, it is not particularly comfortable to wear on the thigh. Its edges are relatively sharp and the manufacturer-provided attachment method (small elastic belt around the thigh) is likely to be uncomfortable to wear during day-to-day activities (Edwardson et al., 2016a). Furthermore, the device is relatively thick (Figure 3.1) which may make it quite conspicuous underneath clothing. This may result in participants removing the device in social situations, further reducing compliance.

Figure 3.1. Side-by-side comparison of the dimensions of the ActiGraph GT3X (left), activPAL 3 (middle), and activPAL micro (right).

3.3.1.4 Summary

In summary, the thigh-worn Actigraph has acceptable validity for the measurement of sedentary time. However, it has only been validated in laboratory settings; whether its validity extends to free-living contexts is unknown. Furthermore, there are issues in the practicality of wearing the Actigraph on the thigh: it is not waterproof, and is likely to be uncomfortable and conspicuous, potentially reducing participants' compliance with the device.

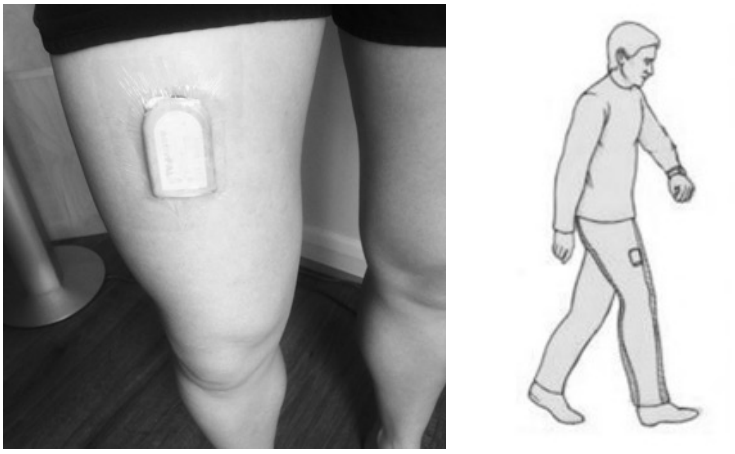
3.3.2 activPAL

The activPAL (PAL Technologies, Glasgow, UK)[15] is a small, tri-axial accelerometer that is worn on the midline of the anterior thigh and is affixed to the skin using non-allergenic adhesive (Figure 3.2). Using a proprietary algorithm ('intelligent activity classification'), the activPAL classifies postural and movement status by integrating the thigh's orientation in combination with acceleration. From this information, the activPAL can record an individual's static posture (sitting/lying or standing) and movement (stepping), including movement intensity (step cadence). By default,

[15] The activPAL3 and activPAL micro are described here jointly. These two models differ only in size (the micro is smaller) and recording capacity (the 3 has larger capacity); the technological specs between the two are identical.

recordings are taken at a frequency of 20Hz (20 readings per second) and an 'event' (sitting, standing, or stepping) that lasts for a minimum of ten seconds will register on the device.

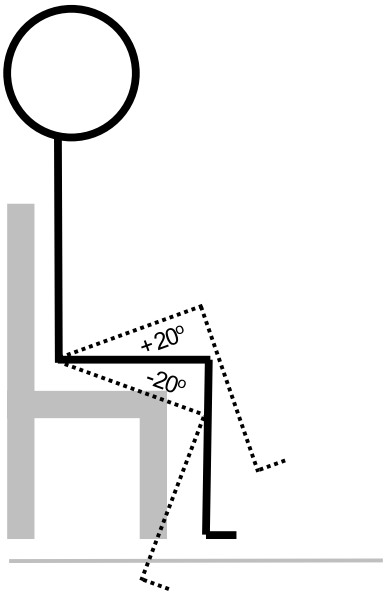
Figure 3.2. The activPAL attached to the midline of the anterior thigh.



3.3.2.1 Sedentary measurement details

The activPAL identifies sedentary time when the thigh is stationary and horizontal. The angle of the thigh must be less than 20 degrees above or below the horizontal plane (0 degrees) in order to be classified as sitting/lying down (BASSETT et al., 2014); if the thigh is tilted beyond 20 degrees while stationary, the posture will be classified as standing (Figure 3.3). As with the thigh-worn Actigraph, the activPAL does not distinguish between sitting and lying down, so these are classed together. By default, the proprietary algorithm assigns a MET value of 1.25 to all sitting/lying events, meaning that physical activities done in a seated position (e.g., weight lifting) will register as a standard sitting/lying event even though their actual MET values are higher and would warrant classification as light or moderate activity.

Figure 3.3. Diagram depicting the activPAL's classification of sedentary time. If the thigh is within 20 degrees relative to the horizontal (between the dotted lines) and stationary, the posture is classified as sitting/lying down.



3.3.2.2 Evidence of validation

The activPAL has been validated for the measurement of sedentary time, based on laboratory-based experiments and free-living validation studies. In laboratory-based validation studies, each study reported ≥95% agreement between the activPAL's overall measurements of sedentary time compared to the criterion measure of direct observation (Edwardson et al., 2016a, Grant et al., 2006, Steeves et al., 2015, Lyden et al., 2017).

Two laboratory-based studies have tested the accuracy of the activPAL in classifying a wide variety of lying and sitting postures (summarised in Table 3.1) and reported high agreement with direct observation in overall lying and seated postures (100% and 91% agreement, respectively), although accuracy was lower in less-common variations of sitting that involve extension of the legs (e.g., sitting on a tall stool) (Edwardson et al., 2016a, Steeves et al., 2015).

Table 3.1. Accuracy of the activPAL's and thigh-worn Actigraph's classifications of various seated and lying postures in laboratory-based studies. Mean (95% CI) accuracy is reported for each posture against direct observation (criterion measure).

Study	Experimental condition	Mean (95% CI) percentage of posture coded correctly compared to direct observation	
		activPAL	**Thigh-worn Actigraph**
Edwardson et al., 2016	**All lying activities**	**100 (100.0 – 100.0)**	**93 (89.1-97.4)**
	Lying flat on back, legs straight	100 (100.0 – 100.0)	100 (100.0–100.0)
	Lying on back, legs bent	100 (100.0 – 100.0)	73 (57.7–88.4)
	Lying on side, legs straight	100 (100.0 – 100.0)	100 (100.0–100.0)
	Lying on side, legs bent	100 (100.0 – 100.0)	100 (100.0–100.0)
	All sitting activities	**91 (87.1 – 94.3)**	**99 (98.4-100.3)**
	Sitting on chair, knees 90°, feet flat on floor	100 (100.0 – 100.0)	100 (100.0–100.0)
	Sitting on chair, legs crossed (leg with activPAL crossed over leg without)	100 (100.0 – 100.0)	100 (100.0–100.0)
	Sitting on chair, right foot (on activPAL leg) resting on left thigh	100 (100.0 – 100.0)	100 (100.0–100.0)
	Sitting on chair, legs outstretched, feet flat on floor	42 (24.1 – 59.7)	95 (88.4–102.4)
	Sitting on edge of chair, feet tucked under chair	97 (90.4 – 103.1)	100 (100.0–100.0)
	Sitting on chair, knees 90°, typing at computer	100 (100.0 – 100.0)	100 (100.0–100.0)
	Sitting on chair, knees 90°, playing on smartphone	97 (90.8 – 103.1)	100 (100.0–100.0)
	Standing still	**100 (100.0 – 100.0)**	**100 (100.0–100.0)**
Steeves et al., 2015	**Seated conditions**		
	Self-selected seated posture on 40cm stool	95.2 (85.3 – 100)	100
	Sitting with legs crossed at knee	100	100
	Sitting cross-legged with ankle on opposite knee	100	100
	Sitting with legs outstretched and crossed at the ankle	85.7 (69.4 – 100)	100
	Sitting on 70cm laboratory stool	4.8 (0-14.7)	85.7 (69.4 – 100)
	Standing conditions		
	Self-selected standing posture	100	99.9 (99.8-100)
	Rigid upright posture	100	100

The activPAL has also been found to be highly accurate for the classification of sedentary time in free-living contexts (Hart et al., 2011, Kim et al., 2015a, Kozey-Keadle et al., 2011, Lyden et al., 2012). The findings of these studies, summarised in Table 3.2, indicate the activPAL has high agreement (r ≥0.87), sensitivity (≥95%), and specificity (≥97.5%) compared to the criterion measures (activity logs or direct observation). These results are useful because they indicate that the activPAL can accurately detect sedentary time in everyday environments in which sedentary time can be sporadic, unlike in rigidly controlled laboratory settings.

Table 3.2. Summary of studies that have validated the activPAL for the measurement of sedentary behaviour in free-living contexts.

Study	Sample size and study time frame	Criterion measure	activPAL validity against criterion measure of sedentary time
Hart et al., 2011	n=32 1 day (all waking hours)	Bouchard Activity Record (self-reported activity log)	r=0.87 (p<0.05)
Kim et al., 2015	n=11 1 day (6 hours)	Wearable camera	Sensitivity: 95.01% Specificity: 97.5% Mean absolute percentage of error: 4.11 (95% CI 0.00, 8.42)
Kozey-Keadle et al., 2011	n=19 6 hours	Direct observation	r=0.94
Lyden et al., 2012	n=13 2 days (10 hours each)	Direct observation	r=0.99 (p<0.05)

The activPAL has also been validated for the detection of breaks in sedentary time (i.e., number of sit-to-stand transitions) in both laboratory (Grant et al., 2006) and free-living settings (Lyden et al., 2012). In the laboratory setting, the activPAL's detection of sit-to-stand transitions was in perfect agreement with direct observation (Grant et al., 2006). In free-living environments, the activPAL's recorded number of breaks was strongly correlated with the number recorded during direct observation (r=0.90-0.97)(Lyden et al., 2012). Thus, in addition to being a valid tool for the measurement of total sedentary time, the activPAL is sensitive enough to detect interruptions in sedentary time.

The activPAL has not been formally validated for the measurement of sedentary time during pregnancy, although there is no reason to expect its measurements to be affected by morphological changes during pregnancy. The activPAL has been used in one study of pregnant women (DiFabio et al., 2015), and the authors did not report any issues or concerns in their experience of using the device with the pregnant women who participated in that study.

3.3.2.3 Practicalities of wear

The activPAL is a small device that is relatively thin (7mm or 5mm, depending on the model; Figure 3.1) and designed specifically for wearing on the thigh. When attached to the thigh, it is hardly noticeable underneath clothing. One of the activPAL's most attractive features is its option for a continuous, 24-hour wear protocol. The device can be attached to the thigh in a waterproof manner by covering the activPAL with a nitrile sleeve and a piece of waterproof adhesive (Tegaderm) before attaching it to the anterior midline of the thigh with another piece of Tegaderm. This option for continuous wear is likely to increase the likelihood of adequate wear time since the participant does not have to remember to reattach the device every morning upon waking and/or after showering (Edwardson et al., 2016b). However, even with a continuous wear protocol, the wearer may still need to remove the device periodically during the period of wear, either to bathe or swim (since the manufacturer does not recommend submerging the device under water), or if the skin becomes irritated by the device, which is a common occurrence (Edwardson et al., 2016b). Thus, while a continuous wear protocol does not necessarily mean that the device will never be removed during the measurement period, it does substantially reduce the likelihood of non-compliance associated with having to frequently remove and reattach the device.

3.3.2.4 Summary

The evidence presented here indicates that the activPAL is a valid device for the measurement of sedentary time, including breaks in sedentary time, in both laboratory and free-living settings. Importantly, the activPAL may be more acceptable to wear since it is slim and designed to be worn on the thigh (with a continuous-wear option), which may increase participants' compliance with the device.

3.3.3 Conclusion

The evidence presented here suggests that while the Actigraph (waist- and wrist-worn) is the most commonly used device to measure sedentary time in population-based studies, it has limited validity in the assessment of posture. The thigh-worn Actigraph has been validated for the measurement of posture, but it has not been used in free-living contexts. There are also concerns about the practicality of wearing the Actigraph on the thigh, which has not yet been done in free-living settings. In contrast, the activPAL has been validated in free-living studies and has a longer history of use in studies focused on the free-living measurement of sedentary time. The practicalities of wearing the activPAL are also attractive, as it can be worn continuously, is small and discreet, and is designed to be worn comfortably on the thigh. For all of these reasons, the activPAL will be used for the objective measurement of sedentary time in this study.

3.4 Objective methods for the measurement of physical activity

In addition to measuring sedentary time, this study aims to measure physical activity as a control variable. The activPAL is capable of measuring stepping time and MVPA, and using it in this capacity is appealing so that one device can be used to measure both sedentary time and physical activity, reducing the burden for both the participant and the researcher (Matthews et al., 2012b). To this end, the way in which the activPAL measures physical activity is described below, followed by an assessment of its validity in doing so.

3.4.1 activPAL's measurements of physical activity

The activPAL has been used by other studies to measure physical activity either by its measurement of stepping time (Smith et al., 2015, Pulakka et al., 2018, Dall et al., 2017, Craft et al., 2012, de Rooij et al., 2016) or MVPA (Craft et al., 2012, van der Berg et al., 2016a). The activPAL's proprietary algorithm registers stepping time if the wearer maintains a minimum stepping cadence of 20 steps per minute for at least 10 seconds. MVPA is classified as time spent stepping at a cadence of at least 100 steps per minute (which must be sustained for at least 10 seconds to register).

3.4.2 Validation of activPAL for measurements of physical activity

The activPAL has been validated for the measurement of both stepping time and MVPA. Compared to the criterion measure of direct observation within a laboratory setting, the activPAL has shown near-perfect agreement in its classification of stepping at a range of speeds and conditions (see Table 3.3 for details), indicating that it is a valid tool for the measurement of stepping time (Steeves et al., 2015, Edwardson et al., 2016a).

Table 3.3. Summary of the studies that have validated the activPAL for the measurement of walking in a laboratory setting.

Study	**Walking condition**	**Mean time coded correctly (% (95%CI)) compared to direct observation**
Steeves et al. (2015)	Overground slow walking pace	100
	Overground normal walking pace	98.5 (95.5-100)
	Stair descending	95.1 (90.9-99.4)
	Stair ascending	95.1 (91.3-98.9)
	Treadmill at 0.67ms^{-1}	100
	Treadmill at 1.12ms^{-1}	100
	Treadmill at 1.56 ms^{-1}	100
	Treadmill at 2.45 ms^{-1}	100
	Treadmill at 2.91ms^{-1}	100
Edwardson et al. (2016)	Self-paced free-living walk	97 (94.2-99.9)

The activPAL measures MVPA by assigning metabolic equivalents (METs) to stepping cadence using a proprietary equation. Based on this equation, MVPA (≥3.0METs) is determined when step cadence exceeds 100 steps per minute. The activPAL's measure of step cadence has been validated as it showed high agreement compared to video analyses (mean bias of 0.3 steps (95% limits of agreement -3.3 to 3.9 steps) (Harrington et al., 2011). On a continuous scale, the activPAL's assignment of METs to various stepping cadences has had low validity compared with indirect calorimetry (Harrington et al., 2011). However, the activPAL has been validated for its *classification* of MVPA (as time spent stepping at a cadence that registers ≥3.0 METs) in a free-living setting using direct observation as the criterion measure (ICC

0.98 (95%CI 0.95 to 0.99) (Lyden et al., 2017). Thus, the activPAL is a valid tool for the measurement of time spent in MVPA.

It is important to note that the activPAL has not been validated for the measurement of MVPA specifically during pregnancy. This may be critical because there is evidence to suggest that various gait parameters (including step cadence) change during pregnancy (Forczek et al., 2018), alongside evidence to suggest that the relationship between walking speed and METs during pregnancy may be atypical due to pregnancy-specific metabolic adaptations (Byrne et al., 2011). Thus, whether the application of the activPAL's classification of MVPA based on stepping cadence is valid for use during pregnancy is not clear. However, there is no reason to suspect that pregnancy would alter the activPAL's measurement of stepping time, which is registered if a minimum cadence of 20 steps per minute is detected (if the stepping 'event' lasts at least 10 seconds). Therefore, the activPAL's measure of stepping time was used as an indicator of physical activity in this study.

3.4.3 Conclusion

In order to simplify the protocol and require participants to wear only one device, the activPAL's measurements will be used for the assessment of both sedentary time and physical activity. The evidence presented in this section suggests that the activPAL is a valid tool for the measurement of physical activity, either as stepping time or MVPA. Because the validity of the activPAL's measurement of MVPA is unknown during pregnancy, stepping time will be used as an indicator of physical activity in this study.

3.5 Methodological decisions for collecting and processing activPAL data

When using the activPAL to measure sedentary time and physical activity, a number of decisions are required in order to define the measurement duration, define a valid day, remove non-wear and night-time sleep data, and accurately summarise the data. The rationale and decisions made in each of these areas are described below.

3.5.1 Defining the measurement duration

As in all accelerometry studies, it is necessary to determine the minimum number of days that the activPAL must be worn in order to ensure that the 'typical' sedentary

patterns of each individual are adequately captured. Sedentary time is somewhat variable from day to day within individuals, although less so than MVPA (Barreira et al., 2016). Studies using generalisability theory have suggested that four days of measurement yield high intra-individual reliability (intra-ICC of 0.80) (Barreira et al., 2016), indicating that an individual's 'typical' pattern of sedentary time should be detectable in four days of measurement.

Although four days of measurement will provide sufficient information, a wear duration of seven days is standard practice in accelerometry studies measuring sedentary time (Healy et al., 2011a, Healy et al., 2008a, Matthews et al., 2008, Edwardson et al., 2016b). A seven-day protocol not only improves the validity of the measurements (Barreira et al., 2016), but also creates a buffer so that individuals' data sets will be valid even if the participant does not perfectly comply with the wear protocol (i.e., if they fail to wear it for three days). Therefore, the measurement duration for this study was seven days, and four days of valid wear were required for a data set to be valid. While it is standard practice to require at least one weekend day in studies measuring MVPA (Matthews et al., 2002, Matthews et al., 2012b), sedentary time has been shown to be consistent between weekdays and weekend days (Smith et al., 2015), thus it was not a requirement that one of the four valid days of measurement be a weekend day in this study.

3.5.2 Defining minimum wear-time per day

Traditionally, accelerometry studies focused on the measurement of sedentary time (via Actigraph) have used waking-wear protocols in which participants were instructed to remove the device during night-time sleep. Waking-wear protocols therefore require the wearer to remove and reattach the accelerometer every day; this comes with a risk of biased wear-time, such that participants are more likely to wear the device during more active periods of the day and systematically not wear the device at the beginning and end of the day, where sedentary time is likely to be the highest (McVeigh et al., 2016, Tudor-Locke et al., 2011a, Bellettiere et al., 2015). A minimum waking wear criterion of 10 hours is commonly used to define a valid day in such studies (Matthews et al., 2008, Healy et al., 2011b, Healy et al., 2008a, Kozey-Keadle et al., 2012, Henson et al., 2013a), although it has been suggested that 14 hours of waking wear are required to reduce the bias associated with selectively

wearing the accelerometer during more active times of the day (Herrmann et al., 2013, 2014).

In contrast, among studies that use a continuous-wear (24-hour) protocol such as this study, selection of a minimum wear criterion is less sensitive to the possibility of biased non-wear time because the participants are wearing the device continuously. This is not to say that participants never remove the device in a continuous wear protocol, but that non-wear is much less likely to be systematically patterned. To this end, the minimum wear criterion does not need to be set to minimise the risk of bias in the same way as a waking-wear protocol; rather, it simply needs to be set to identify and remove 'incomplete' days in which the device was clearly not worn for a substantial proportion of the day. Studies that use a continuous-wear protocol typically require a minimum wear of 10 waking hours for a day to be considered valid (Edwardson et al., 2016b, de Rooij et al., 2016); this criterion was applied in this study as well.

3.5.3 Removal of night-time sleep and incomplete days of wear

In accelerometry studies that use a continuous-wear protocol, night-time sleep and incomplete days of wear must be removed from the data. Doing this accurately is particularly crucial for studies focused on sedentary time because night-time sleep and non-wear can be misclassified as sedentary time (or vice versa) if not correctly identified and removed. It should be noted that it is common practice to leave brief periods of non-wear (e.g., for 15 minutes to take a bath) or short stretches of sleep (e.g., an afternoon nap) in the data set, due to the complexities of identifying these occurrences (and reliance on the accuracy and completeness of participants' diaries) without introducing additional measurement error (Alex Rowlands, personal communication).

There are two main approaches generally accepted for the identification and removal of night-time sleep and days of incomplete wear in accelerometry data sets: manually or through an automated algorithm. The manual approach relies on participants' diaries to indicate when the participant went to bed each night and woke up each morning (night-time sleep) and if/when the device was ever removed for a prolonged period of time (non-wear). This diary is juxtaposed with the raw accelerometry data and, assuming they match, the sleep data are removed

accordingly (Matthews et al., 2013, Barreira et al., 2016, Rosenberg et al., 2015, Swartz et al., 2014). However, in many cases, participants do not remember to provide this information each night or they provide rough estimates, leaving it up to the researcher to identify these periods. There are several approaches to doing this, summarised in Table 3.4. Night-time sleep may be especially difficult to accurately isolate manually if sleep diaries are unavailable due to the fact that many adults engage in a period of sedentary time prior to going to bed (e.g., watching television), and/or individuals get up in the middle of the night (e.g., to use the toilet). Thus, there is some decision-making required to identify where sleep time begins and ends. For this reason, applying an automated algorithm can aid the process of isolating and removing sleep and non-wear; available algorithms are discussed in the next section.

Table 3.4. Summary of sleep and non-wear determination criteria that have been applied to activPAL data using manual protocols.

Sleep determination criteria	**Study**
Sedentary time between midnight and 06:59	Smith et al. (2014)
The beginning of night-time sleep as the last standing event before a period of >3 hours of sitting/lying after 22:30, and the end of night-time sleep (waking) as the first standing event after ≥2 hours sitting/lying between midnight and 09:00	Chastin et al. (2014)
Non-wear determination criteria	
90 minutes of consecutive zero accelerometer counts, allowing for 2-minute intervals of non-zero counts bookended by 30-minute consecutive zeroes	Choi et al. (2011)
60 minutes of consecutive zeroes with interruptions of 2 minutes or less	Matthews et al. (2013)
Bouts of >8 hours sitting or lying during waking hours	Godfrey et al. (2014)
>3 hours of continuous 0 or 1 counts	Barreira et al. (2016)

3.5.3.1 Automated algorithm

An algorithm written for use in STATA or SAS has recently been validated for the removal of sleep and prolonged non-wear in continuous-wear activPAL data sets, using the 'EventsXYZ.csv' files produced by the activPAL software (Winkler et al., 2016). This algorithm's greatest strength is the fact that it was developed from data obtained from one free-living study (the STAND study, n=187 activPALs with

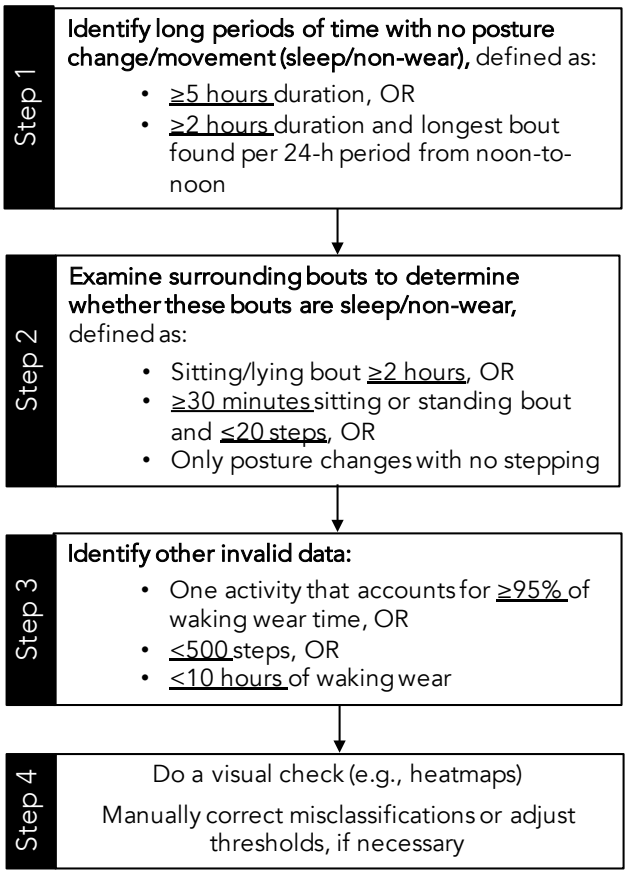
completed wear/sleep diaries) and was validated by applying it to an independent data set from a separate study (AusDiab study, n=782 activPALs with completed wear/sleep diaries). When the algorithm's identification of sleep and prolonged non-wear was compared to participants' diaries in the AusDiab study, the algorithm had sensitivity of 0.95 (95% CI 0.89, 0.98), specificity of 1.00 (95% CI 0.98, 1.00), and kappa (chance-corrected agreement) of 0.94 (95% CI 0.88, 0.97), suggesting it was able to accurately identify sleep and prolonged non-wear without also inadvertently removing valid waking wear. It should be noted that this is not the only algorithm designed to remove invalid data from activPAL data sets; however, the other algorithm currently available (van der Berg et al., 2016b) is only designed to identify sleep (not invalid days), and was developed and validated using the same data set which calls its generalisability into question.

The algorithm by Winkler et al. (2016) is designed to identify and isolate waking wear time by removing long periods of non-waking wear, due to either night-time[16] sleep or prolonged non-wear, based on a series of adjustable criteria. The process is diagrammed in Figure 3.4, and the full code is shown in Appendix 2. By default, the algorithm starts by identifying what is likely to be the core of night-time sleep or prolonged non-wear by detecting continuous periods of non-movement lasting ≥5 hours or lasting ≥2 hours and being the longest bout of inactivity per noon-to-noon 24-hour period (Step 1). These criteria enable the algorithm to identify sleep that might not necessarily happen during night-time hours, for example among shift workers, and do not assume that all wearers will necessarily get a full night's sleep every 24-hour period. After identifying this key bout of sleep or prolonged non-wear, the bouts immediately on either side of this bout are examined to see if they are likely to be a part of the main sleep/non-wear bout (Step 2). For example, if an individual goes to bed at 10pm, wakes up at 1am to go to the toilet, and returns to bed until 6am, the algorithm would have detected the 1am to 6am bout as sleep in Step 1, but it would also need to recognise that 10pm to 1am was also sleep. The criteria for classifying these surrounding bouts as sleep or non-wear are laid out in Step 2 of Figure 3.4. Finally, invalid days of measurement that would not have necessarily been detected through Steps 1 and 2 must also be identified and removed

[16] 'Night-time' is used here to refer to the main block of daily sleep (i.e., not including naps), although the algorithm does not assume that not everybody's daily sleep occurs overnight.

(Step 3); by default, these are defined as one activity accounting for ≥95% of waking wear time, fewer than 500 steps taken in a day, or fewer than 10 hours of waking wear.

Figure 3.4. Flow chart of the STATA algorithm for removal of sleep and non-wear. The underlined numbers indicate modifiable thresholds; the default values (used in this study) are shown here. Modified from Winkler et al., 2016.

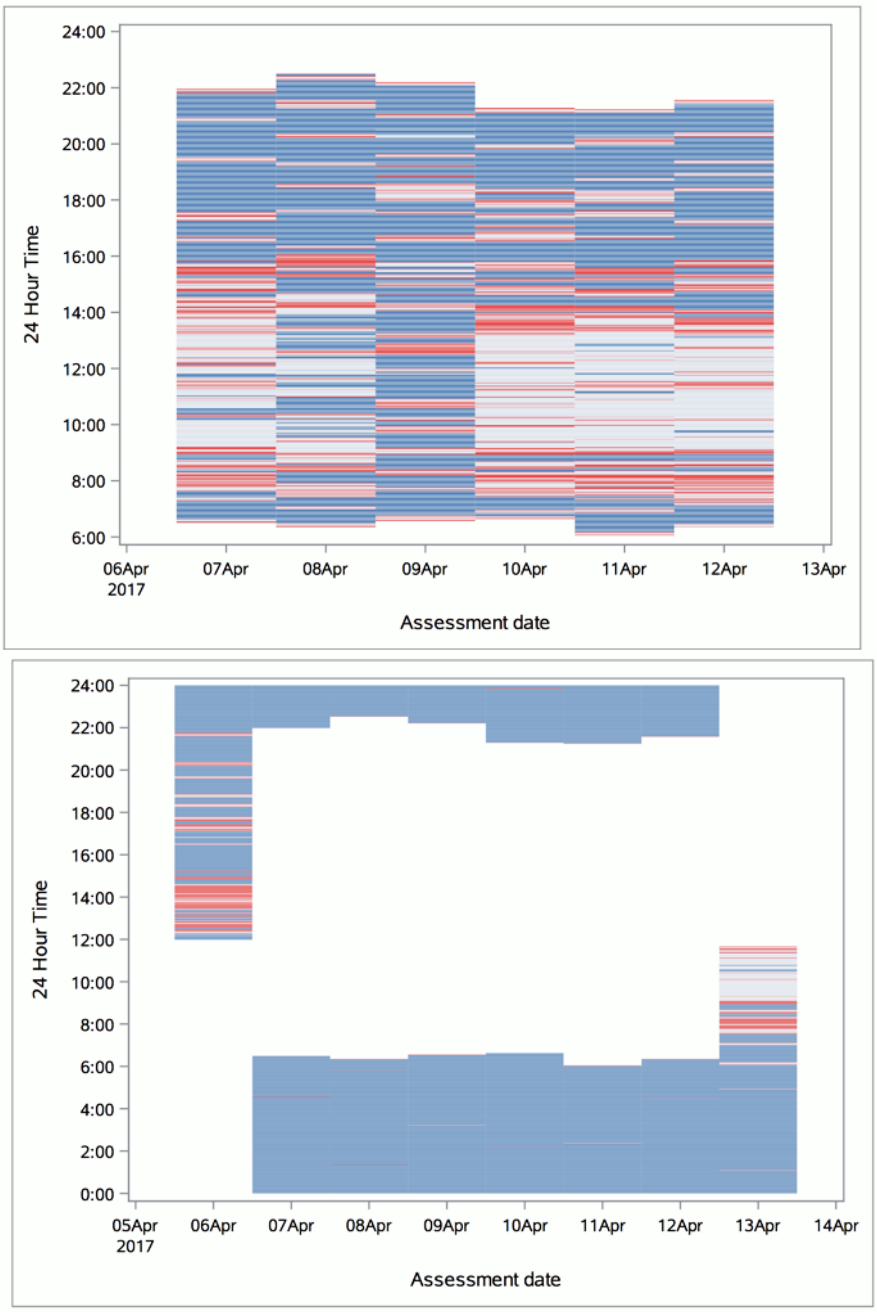


3.5.3.2 Quality control

When using an algorithm to automatically detect and remove sleep and non-wear time, it is essential to ensure that the process has accurately removed all invalid data without also removing any valid data (or vice versa), especially when evaluating whether the algorithm's default criteria are appropriate for a given sample population. One recommended method to assess this is to create heat maps to visualise the results of the algorithm in order to assess whether it appears that only and all invalid data were removed (Edwardson et al., 2016b). A SAS code has been made available to generate heat maps for activPAL data after they have been processed using the algorithm listed above (see Figure 3.5 for example). Each heat map should be carefully examined for spurious classifications, alongside

participants' sleep/non-wear diaries if possible. The process for checking and, if necessary, manually correcting such instances is described in the following section.

Figure 3.5. Heat maps showing valid waking wear (top) and invalid or sleeping wear (bottom) which was removed by the algorithm for one individual's wear period. In this example, the algorithm has removed the first and last partial days of wear (recording started and stopped at 12.00) and has detected and removed sleep from around 10.00pm until around 6.00am (which matched the times in the diary). The bands indicate postures.



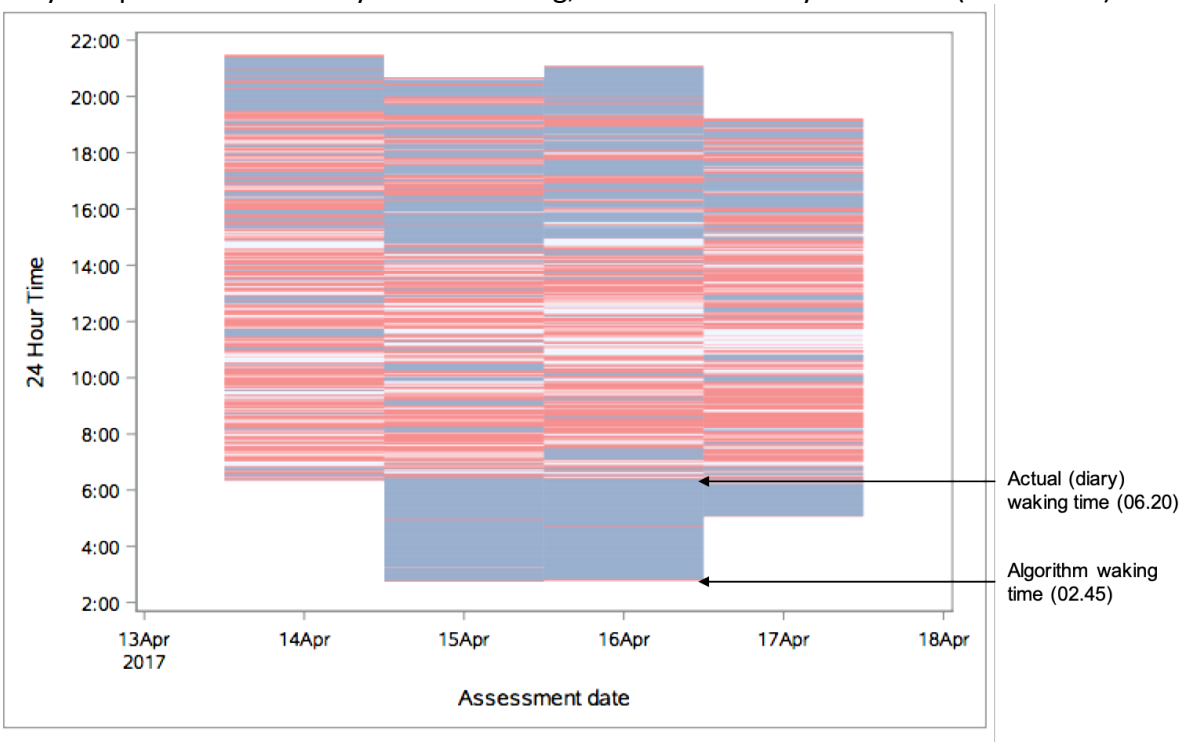
3.5.3.3 Manual corrections

If heat maps indicate obvious inaccuracies upon visual inspection, the sleep/non-wear diary of the wearer should be consulted, if available. Figure 3.6 is an example of such a case: on two days, the algorithm has determined waking time to be around 02.45, which not only seems unusually early but also does not appear to be characterised by movement patterns consistent with the remainder of the day. Consultation of the participant's wear diary indicates that the waking time was actually 06.20 which appears reasonable on the heat map and suggests what the algorithm had flagged as waking time was just a short interruption in sleep (e.g., trip to the toilet). Very little exists in the literature about how to manually correct such instances. The only available suggestion is that if ≥50% of an accelerometry bout fits within self-reported waking time, then it should be classed as such (Winkler et al., 2016). For example, if the participant indicates on the diary that she woke up at 06.00, a bout lasting from 05.45 to 07.00 would be classed as awake but a bout from 05.00 to 06.15 would not. It should be noted that manual corrections are intended to fix misclassifications by the algorithm that are obvious enough to visually identify on a heat map, as in the case of Figure 3.6. Given that participants' diaries usually provide *estimates* of sleep and wake times (Edwardson et al., 2016b), smaller discrepancies between the algorithm and diary (e.g., <1 hour) could probably be ignored, although there is no available literature to define this threshold.

The end of the sleep algorithm STATA code has several lines where manual corrections can be entered (specifically, lines where the ID numbers of the bouts that need reassignment from sleep to waking or vice versa can be entered). After completing manual corrections, heat maps should be generated again to check that the manual corrections resolved the discrepancy.

It should be noted that although the algorithm is an 'automated' method for removing sleep and invalid days from activPAL data sets, it is used in this study as a *starting place* for the identification and removal of sleep and invalid data, especially since it is unknown how the accurate the algorithm may be in the identification of sleep time during pregnancy (e.g., if sleep is frequently interrupted to go to the toilet). This is described further is Chapter Four (section 4.7.2.2).

Figure 3.6. Heat map of valid wear as determined by the algorithm prior to manual correction. On two days, the algorithm incorrectly identified waking time as what was more likely a trip to the toilet early in the morning; this was manually corrected (not shown).



3.5.3.4 Key output measurements

After removal and corrections of night-time sleep and other invalid data, the measurements of sedentary time and stepping during valid waking wear need to be summarised into meaningful variables (e.g., total sedentary time per day). As with removal of invalid data, summarisation of valid data can be done manually or via algorithm. Given that each participant's activPAL data is usually thousands of rows, algorithms or other custom-written programmes are customarily used to automate the process (Edwardson et al., 2016b, de Rooij et al., 2016).

An algorithm for the summarisation of the remaining valid data set is available for use in STATA and was developed by the same group that designed the sleep/non-wear algorithm (Winkler et al., 2016). Unlike the sleep/non-wear algorithm, this algorithm does not require or make any 'decisions'; it simply summarises the postural classification from the activPAL's proprietary algorithm for the periods of waking wear determined by the sleep algorithm.

The algorithm produces a number of output variables, including sedentary time, stepping time, standing time, waking time, prolonged sedentary time (sedentary

time accumulated in an uninterrupted bout lasting ≥30 minutes), number of sit-to-stand transitions (breaks in sedentary time), and number of valid measurement days. By default, the algorithm provides these variables for each valid measurement day, followed by the mean for each participant (sum of each variable on each valid day, divided by the number of valid days). Optional codes in the algorithm allow the same variables to be produced for each hour, for selected portions of the day (e.g., evening hours only), or separately for weekdays and weekend days.

3.5.4 Conclusion

In this study, activPAL data sets were considered valid if they contained at least four valid days of measurement, defined as at least 10 hours of waking wear. Data were processed using an automated algorithm that has been validated for the removal of night-time sleep and invalid or incomplete measurement days in activPAL data sets. The algorithm's classifications were visualised using heat-maps and checked against diaries (where available); manual corrections were applied in cases in which the algorithm's classifications were clearly incorrect, with heat-maps re-run to check that the manual corrections resolved any discrepancies with the diaries.

3.6 Subjective measurements of time spent in selected sedentary behaviours

In addition to objectively quantifying sedentary time during pregnancy, a secondary aim of this study is to examine how time is allocated to two of the most commonly-measured sedentary behaviours – television time and occupational sitting time.

There are a number of questionnaires designed to capture time spent in various domains of sedentary time, for example the SIT-Q (Lynch et al., 2014) and the Sedentary Behavior Questionnaire (SBQ) (Rosenberg et al., 2010). However, none of these have been validated for use in a pregnant population. While there is not necessarily a reason to expect that these questionnaires would require special validation for use in pregnancy, there is a general consensus that questionnaires concerning physical activity require special validation for use in pregnancy because of the ways in which domains of physical activity might be unique during pregnancy (Schmidt et al., 2006b, Bell et al., 2013).

At the outset of this project, one of the minor aims of the thesis was to examine how or whether time spent in various physical activity or sedentary domains (e.g.,

household, leisure-time) changed across the course of pregnancy. To this end, four questionnaires validated for use during pregnancy were originally evaluated for use in this study: the modified International Physical Activity Questionnaire (IPAQ) (Aittasalo et al., 2010), Pregnancy Infection and Nutrition 3 (PIN3) questionnaire (Evenson and Wen, 2010a), Kaiser Physical Activity Survey (KPAS) (Schmidt et al., 2006a), and Pregnancy Physical Activity Questionnaire (PPAQ) (Chasan-Taber et al., 2004). The IPAQ was ruled out because sedentary time is assessed as aggregate time spent sitting (hours and minutes per day on weekdays and weekend days, separately) and does not ask about time spent in specific sedentary behaviours. PIN3 was ruled out because it exclusively focuses on physical activity and does not contain any questions related to sedentary behaviours. The PPAQ was originally selected over the KPAS because the PPAQ included questions concerning more sedentary behaviours (which seemed relevant at the time), while the KPAS asked only about television time and occupational sitting time.

The PPAQ asks about time spent in five different sedentary domains, using each trimester as the referent period (see Appendix 3 for full questionnaire). Specifically, the questions ask respondents to report time use for sitting and using a computer, watching television, reading, driving, or sitting at work (see Table 3.5 for original questions with response choices). The PPAQ's criterion validity for the measurement of total sedentary time (using waist-worn accelerometry as the criterion measure) is poor (Spearman correlation coefficients ranged from -0.34 to 0.12, depending upon which Actigraph cut-points were used) (Chasan-Taber et al., 2004). However, the PPAQ was not used in this thesis to measure total sedentary time, but to gauge time spent watching television and time spent sitting at work. The following sections describe the validity of measurements of self-reported television time and occupational sitting time in terms of their *criterion validity*, not their validity as indicators of total sedentary time.

Table 3.5. Pregnancy physical activity questionnaire (PPAQ) questions and response options for time spent in various sedentary behaviours

For this trimester, when you were not at work, how much time did you usually spend:	
Sitting and using a computer, tablet, or writing while not at work?	
None	1 to almost 2 hours per day
Less than ½ hour per day	2 to almost 3 hours per day
½ to almost 1 hour per day	3 or more hours per day
Watching television or films?	
None	2 to almost 4 hours per day
Less than ½ hour per day	4 to almost 6 hours per day
½ to almost 2 hours per day	6 or more hours per day
Sitting and reading, talking, or on the phone while not at work?	
None	2 to almost 4 hours per day
Less than ½ hour per day	4 to almost 6 hours per day
½ to almost 2 hours per day	6 or more hours per day
Driving or riding in a car or bus?	
None	1 to almost 2 hours per day
Less than ½ hour per day	2 to almost 3 hours per day
½ to almost 1 hour per day	3 or more hours per day
In this trimester, how much time did you usually spend sitting at work or at college?	
None	2 to almost 4 hours per day
Less than ½ hour per day	4 to almost 6 hours per day
½ to almost 2 hours per day	6 or more hours per day

3.6.1 Measurement of television time

3.6.1.1 Validity of self-reported television time

Self-reported television time has been shown to have acceptable validity for the measurement of television time. In a sample of 40 overweight and obese adults in the US, self-reported television time (in response to 'How many hours do you watch TV per day, on average?') was not significantly different compared to objective measures (4.3 hours per day versus 4.9 hours per day, respectively; p=0.20) (Otten et al., 2010). However, the authors note that the source of error could either be under-reporting television time, or the television being on without the participant being seated to watch it, which was not rigorously controlled (Otten et al., 2010). In another study, self-reported television time (reported separately for weekdays and weekend days) was compared to activPAL-measured sedentary time annotated with a Bouchard log in which respondents describe their time use for day in 15-minute blocks (Wijndaele et al., 2014a). On the average day, self-reported television time had

strong agreement with the activPAL plus log (rho=0.84); questionnaire-based television time was 1.50 hours per day compared to the criterion measure of 1.22 hours per day (Wijndaele et al., 2014a). Thus, self-reported television time is generally a valid measure of actual television time.

3.6.1.2 Reliability of self-reported television time

Self-reported television time has been shown to have good test-retest reliability. A review by Clark et al. (2009) summarised the findings of studies that had examined the test-retest reliability of self-reported television time among adult samples, reporting ICCs of 0.82 (95%CI 0.75, 0.87), 0.81 (no CIs provided), and 0.92 (95%CI 0.84, 0.96) over test-retest periods of 1 week, 10 days, and 2 weeks, respectively.

3.6.1.3 Data processing

Self-reported television time is processed in a variety of ways, including as a continuous variable rounded to the nearest hour (Stamatakis et al., 2014, Wijndaele et al., 2010, Matthews et al., 2012a, Pinto Pereira et al., 2012, Ford et al., 2010), as tertiles (Thorp et al., 2010, Healy et al., 2008b), or as categorical variables, such as <2, 2-4, or ≥4 hours per day (Dunstan et al., 2010).

A seminal study on the detrimental effects of television time reported a significantly greater likelihood of prevalent type 2 diabetes among those who watched ≥14 hours of television per week, after adjustment for physical activity and other covariates (Dunstan et al., 2004). This finding was corroborated by meta-analysis suggesting that watching less than 2 hours of television per day was linked to increased life expectancy at birth in the US (Katzmarzyk and Lee, 2012). Thus, evidence suggests that greater than 2 hours of television per day may be especially detrimental for a variety of health outcomes.

Given the constraints of this study's data (based on the non-continuous PPAQ response options), television time was dichotomised as less than or at least 2 hours per day. This cut-off has been used previously in pregnancy studies (Oken et al., 2006).

3.6.2 Measurement of occupational sitting time

3.6.2.1 Validity of self-reported occupational sitting time

Self-reported time spent sitting at work (among employed individuals) has also been shown to have acceptable validity. Estimated time spent sitting at work (in response to, 'Please estimate the total time during the last week that you spent sitting down as part of your job while at work or working from home') had good agreement with Actigraph-measured sitting time during working hours (rho=0.39, self-reported sitting time was 0.45 hours higher per day than the Actigraph's measure of 6.8 hours (Clark et al., 2011b)). Correlations between self-reported time sitting at work has also had good correlations against the activPAL with Bouchard log (rho=0.63 (Wijndaele et al., 2014a). Thus, while self-reported occupational sitting time tends to be overestimated, it is generally a valid measure.

3.6.2.2 Reliability of self-reported occupational sitting time

Self-reported time spent sitting at work has demonstrated good test-retest reliability. Among a sample of Australian women, the ICC of two measurements of time spent sitting at work taken around three weeks apart was 0.79 (95%CI 0.73, 0.84) (Marshall et al., 2010). Among a different sample of Australian employees, the ICC was 0.89 (95%CI 0.83, 0.92) based on self-reported measures taken one week apart (Chau et al., 2012a).

3.6.3.3 Data processing

Other studies that have used occupational sitting as a predictor variable have constructed their variables in various ways: less than or at least 24 hours per week (van der Ploeg et al., 2015), less than 1, 1 to 2, 2 to 3, or ≥3 hours per day (Pinto Pereira et al., 2012), 0-15, 15-35, ≥35 hours per week (Stamatakis et al., 2017), or as a continuous measure (Saidj et al., 2013).

Given the constraints of the response options on the questionnaire and the high prevalence of part-time workers in this sample (who may have predominantly sitting jobs but may work fewer hours), the same cut-off as was used for television time (less than or ≥ 2 hours per day) was used here for the sake of consistency. Raw PPAQ responses were also included in subsequent analyses to check that this dichotomisation did not introduce any artefacts or errors.

3.6.3 Conclusion

To measure time spent in the two most common sedentary behaviours, two questions were extracted from the Pregnancy Physical Activity Questionnaire concerning time spent watching television and time spent sitting at work.
Since measures of television time and occupational sitting time have acceptable criterion validity on their own, using responses to these questions in isolation from the rest of the questionnaire does not seem problematic. Cut-offs of less than or at least 2 hours per day were applied for both television time and occupational sitting time.

3.7 Conclusion

Based on the literature reviewed in this chapter, the activPAL was identified as the most suitable device for the measurement of sedentary time in this study because of its measurement validity and its practicality of wear. Measurements of television time and occupational sitting time were extracted from the Pregnancy Physical Activity Questionnaire based on the evidence presented in this chapter suggesting that self-reported television time and occupational sitting time have acceptable validity and reliability.

Chapter Four: Methodology, data processing, and data analysis

This chapter discusses the methods used in this study. It describes the study design, study setting, recruitment and study protocol, regulatory issues, data processing, and statistical and qualitative analyses.

4.1 Study design

This thesis is a prospective, observational study of sedentary time and physical activity among pregnant women who have at least one risk factor for gestational diabetes. It uses a mixed-methods approach, employing accelerometry, questionnaires, and semi-structured interviews to gather both quantitative and qualitative data to measure sedentary time and sedentary behaviours during pregnancy to assess their association with gestational diabetes (GDM) while also aiming to understand the social contexts of sedentary time and physical activity in women's experiences of pregnancy.

4.2 Study setting

This study was based in two hospitals located in the North East of England: Sunderland Royal Hospital ('CHS', City Hospitals Sunderland NHS Foundation Trust) and the Royal Victoria Infirmary ('RVI', The Newcastle upon Tyne NHS Foundation Trust). These hospitals were selected based on their proximity to Durham and their willingness and capacity for the study to take place on the premises. Hospitals were chosen as the main study sites because they serve as a location that nearly all pregnant women routinely visit at least twice during their pregnancies (for their 12-week and 20-week ultrasound scans), and thus represented a central location that provided access to a diverse sample of pregnant women at predictable time points of their pregnancies. The hospitals served as the site of most interactions with participants, including recruiting participants, fitting accelerometers, and administering questionnaires. Descriptive characteristics of each hospital and associated local authority districts are detailed in Table 4.1.

Table 4.1. Descriptive characteristics of the two study sites and associated local authority districts

Study site	Sunderland Royal Hospital (CHS)	Royal Victoria Infirmary (RVI)
Location	Sunderland	Newcastle upon Tyne
Number of births per year (approximation)	3200	5700
Local Principal Investigator	Mr Kim Hinshaw, Consultant Obstetrician and Gynaecologist	Dr Malcolm MacDougall, Consultant in Obstetrics and Maternal Medicine
Index of Multiple Deprivation for local authority district (where 1 is most deprived and 326 is least)[17]	38	92
City population (estimated mid-2016)[18]	277,962	296,478

4.3 Study participants

4.3.1 Inclusion and exclusion criteria

4.3.1.1 Inclusion criteria

The key inclusion criteria for eligibility in this study were that participants had to have a viable pregnancy and had to have a risk factor for gestational diabetes (GDM). The primary reason for requiring a risk factor for GDM was to ensure that each participant would have an oral glucose tolerance test (GTT)[19] which is used to measure glucose levels and diagnose GDM. The risk factors, which are listed in Table 4.2, were used by both hospitals to determine who would require a GTT in accordance with the National Institute for Health and Care Excellence (NICE) guidelines (National Institute for Health and Care Excellence, 2015). Participants were required to have at least one risk factor to be eligible for this study, although some participants had more than one.

[17] Data retrieved from https://www.gov.uk/government/statistics/english-indices-of-deprivation-2015

[18] Data retrieved from https://www.ons.gov.uk/peoplepopulationandcommunity/populationandmigration/populationestimates/datasets/populationestimatesforukenglandandwalesscotlandandnorthernireland

[19] The UK no longer does universal GDM screenings due to findings that indicate it is not cost-effective to do so (Jacklin et al. 2017). Instead, the GTT is only routinely offered to women with at least one risk factor for GDM as listed above.

Table 4.2. Risk factors for GDM based on 2015 NICE guidelines

Risk factors for gestational diabetes
BMI ≥30kg/m^2
First-degree relative (i.e., parent or sibling) with Type 1 or Type 2 diabetes
Previous gestational diabetes
Previous macrosomic baby (≥4.5kg at birth)
Ethnicity associated with higher incidence of diabetes (e.g., South Asian, Black Caribbean)

In addition to these criteria, participants had to be at least 18 years old[20]. They also had to be fluent speakers and readers of English in order to be able to give informed consent and complete the questionnaires. Finally, they had to be between 11 and 15 weeks' gestation at the time of recruitment to ensure they had adequate time to consider participation in the study prior to their 20-week scan.

4.3.1.2 Exclusion criteria

Exclusion criteria were selected to prevent the recruitment of participants whose data might be highly unusual or invalid. Individuals expecting more than one baby (e.g., twins or triplets) were ineligible since expecting twins or triplets is associated with significantly higher risks for a wide range of pregnancy complications (Blickstein, 2005). Individuals with previously diagnosed type 1 or type 2 diabetes were ineligible because diabetes diagnosis prior to pregnancy means that individual cannot possibly go on to develop GDM. Individuals taking medication to manage chronic hypertension (e.g., ACE inhibitors or beta-blockers) at the time of recruitment were ineligible because of the way that the medicine could alter their physiology, particularly in relation to the blood pressure outcome variable.

4.3.2 Sample size

The minimum sample size for the main quantitative (accelerometry) component of this study was calculated using G-Power (version 3.1.9.2) in relation to the hypothesis that sedentary time will be associated with risk of gestational diabetes, which is the key outcome variable. The calculation was two-tailed, power=0.80, and alpha=0.05. The probability of the outcome when the predictor values are set to the

[20] The original study protocol set an upper age limit of 40 based on evidence suggesting that pregnancy complications may be higher outside of that age range (Cleary-Goldman et al., 2005); however, several (n=5) participants were recruited to the study before the research team realised they were over 40 years old; they were retained in the study and analyses.

mean (Pr(Y=1 | X=1)H0) was set at 0.134 to reflect the incidence of gestational diabetes in Sunderland among women who have a risk factor and are screened (13.4%, obtained through personal communication with Rahul Nayar, Consultant at CHS). The odds ratio used in the calculation was 1.73 based on a meta-analysis describing the risk of developing the metabolic syndrome in relation to sedentary (mostly television[21]) time using the 'most-adjusted' odds/risk ratios from the included studies (Edwardson et al., 2012). This odds ratio was chosen because, at the time, this was one of two meta-analyses available; the other (Wilmot et al., 2012) included studies that only measured television time in relation to type 2 diabetes incidence, reporting an effect size of 1.89. Thus, the effect size reported by Edwardson et al. (2012) was used because it was the more conservative estimate of the two, and because it was based on more varied measures of sitting than just television time. The results of this analysis indicated a minimum required sample size of 228[22]. The recruitment target was set at 326, which allowed a drop-out rate of 30% which has been reported in studies using similar methods (DiFabio et al., 2015, Kozey-Keadle et al., 2012). I conducted the power analysis, and it was reviewed and confirmed by Dr Tessa Pollard and Dr Adetayo Kasim (research statistician, Durham University).

4.4 Recruitment

4.4.1 Identifying eligible participants

The secretaries for the research midwives' offices at both hospitals identified eligible participants by evaluating the booking proformas submitted to the hospital in the early stages of antenatal care. The booking proformas, which contain details about health history, pregnancy history, and family history, are completed by women at the very beginning of their pregnancies and reviewed with their midwives at their first antenatal booking appointment before being submitted to the hospital that will be providing their care. The secretaries evaluated the completed proformas alongside the list of inclusion and exclusion criteria to identify eligible participants.

[21] The meta-analysis by Edwardson et al. (2012) contained 10 studies with the following measures of sedentary time: accelerometry (n=1), subjective total sitting (n=1), television (n=5), television + computer (n=2), television + computer + reading (n=1).

[22] For reference, the other effect size that was not used (1.89) indicated a minimum required sample size of 170.

The dating scan appointments of women who appeared to meet the eligibility criteria were put in the study diary at each site.

4.4.2 Approaching and consenting participants

Potentially eligible participants who had been added to the study diary were approached in the waiting room when they attended for their 12-week dating ultrasound scan[23] between February and August 2017. The member of the research team (i.e., research midwife, clinical trials assistant, or myself) introduced herself and told the potential participant that there was an ongoing study for which she might be eligible. If the woman approached was happy to learn more about the study, she was given the Participant Information Sheet (Appendix 4) to read, which detailed the aims of the study and what participation would involve. Following her scan and confirmation from the sonographer that the pregnancy was viable, singleton, and between 11 and 15 weeks' gestation, the potential participant was followed-up in the waiting room and asked if she had a chance to read the information and if she would like to take part. If she was interested and eligible, she was taken a private consultation area where the study was further explained, an opportunity to ask questions was provided and, if she was happy to participate, written consent was taken[24] (Appendix 5).

4.4.3 Withdrawal

Women who expressed a desire to stop participating in the study at any time for any reason were withdrawn. Prior to each contact with participants, the hospital system was checked to confirm that the participant's pregnancy was progressing successfully; participants were administratively withdrawn (and not contacted) if there was evidence on the system to suggest they no longer had a viable pregnancy due to miscarriage, intrauterine death, or significant foetal abnormality. Participants were also administratively withdrawn if they changed hospitals before their 20-week scans or if they could not be reached after three attempts to contact.

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[23] The dating scan typically happens at 12 weeks' gestation, but can take place between 11 and 14 weeks.

[24] NHS ethics normally requires that potential participants have at least 24 hours between approach and consent, but this was waived due to the study design (see full discussion in section 4.6.1).

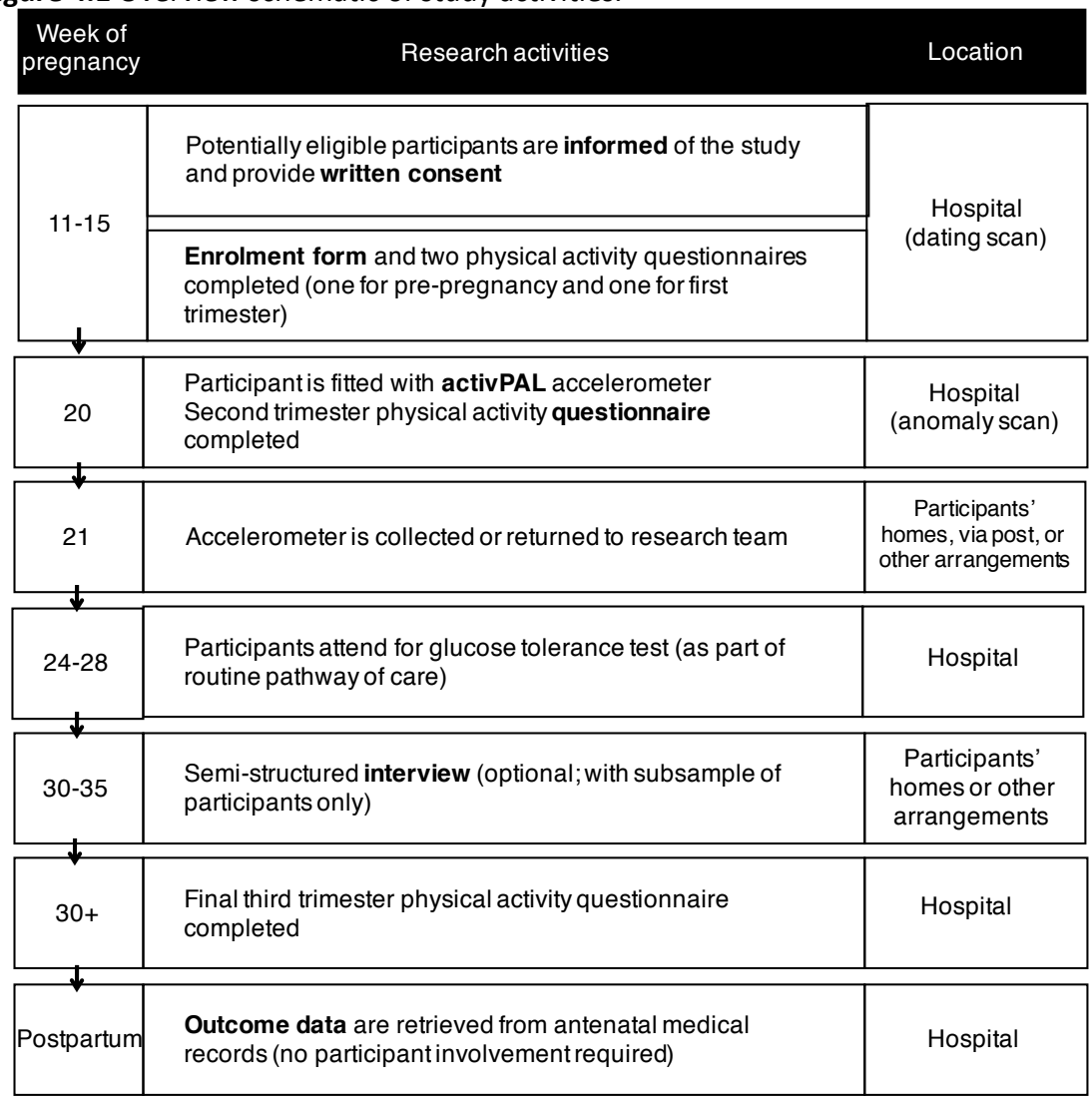
Participants were told in the Participant Information Sheet that if they wished to withdraw from the study, they could request that their data provided up until that point be destroyed; however, no withdrawn participants made this request. Therefore, the data provided up until the point of withdrawal was kept in the database so that descriptive statistics for the entire sample population could be reported and so that demographic comparisons could be made between those who withdrew and those and who did not.

4.5 Study protocol

4.5.1 Overview

A visual schematic of the study protocol can be found in Figure 4.1. Each of the study activities shown in the schematic are described individually in more detail in the following sections.

Figure 4.1 Overview schematic of study activities.



4.5.2 Enrolment form

An enrolment form (Appendix 6) was administered to consented participants following their dating scan ultrasound appointment. The completion of this form served three primary purposes. First, the details provided on the form confirmed the eligibility of the participant for the study (e.g., confirmed that the participant does not have type 1 or type 2 diabetes). Second, the form asked participants to provide contact details and preferred mode of contact so the research team had the information and permission necessary to follow-up with the participant at each stage of the study. Finally, the form asked a series of basic demographic questions which provided data to be reported in descriptive statistics or to be included as statistical co-variates. These data include maternal age, ethnicity, birth country, education,

marital status, income category, number of previous full-term pregnancies, number of children at home, employment status, job title (if employed), pre-pregnancy BMI category, smoking status, incidence of previous GDM, and whether an immediate family member (parent or sibling) has diabetes.

4.5.3 Accelerometry

All accelerometry took place between late March and early November 2017. After receiving confirmation from the research midwives' secretaries that the pregnancy was still normally progressing, participants were contacted the week before their scheduled 20-week scan to check that they were happy to continue in the study. If they agreed to continue and if the 20-week scan indicated normal development, they were seen immediately following the scan to be fitted with an activPAL accelerometer (see Chapter Three for the rationale for using this device). The fitting, which usually took about ten minutes, took place either in a counselling room or a private examination room within the antenatal clinic, depending on room availability (Figure 4.2). The participant was shown where the activPAL was going to be placed and how it was going to be attached. With her permission, the device was attached to the anterior midline of her right thigh using an 10x8cm sheet of 3M Tegaderm dressing.

Figure 4.2. The counselling room (a) and examination room (b) within the antenatal clinic at CHS where accelerometry fittings took place

Once the device was attached, written instructions describing the wear protocol for the device were verbally explained (Appendix 7). The participant was asked to wear

the device for seven days for 24 hours per day[25]. Participants were instructed to remove the device prior to bathing or swimming, but to leave it on in the shower and while they slept. The instruction sheet they were given detailed how to reattach the device if they removed it. Participants were told that if the dressing mildly irritated their skin, they could move the accelerometer to the same spot on the opposite leg, but that they should completely remove the device if the irritation was moderate to severe. Each participant was told that the goal of the research was to measure their everyday movement patterns, and they were encouraged to keep their activities as normal as possible as they wore the device. My contact details were provided on the sheet and participants were told to contact me in the first instance if they had any questions or if they required additional pieces of dressing. Finally, participants were given a diary to fill in during the week of wear (Appendix 7) which contained spaces to record whenever they removed the device and why (e.g., for a bath, due to irritation) as well as to record naps and night-time sleep. The instruction sheet, sleep and non-wear diary, and three pieces of extra dressing were sent home with them in a zipper bag (Figure 4.3).

[25] The device was programmed to begin recording 30 minutes after the anomaly scan appointment time and to finish recording exactly seven days after that (e.g., if the scan was at 11.00 on Tuesday, recording went from 11.30 on Tuesday until 11.30 the following Tuesday)

Figure 4.3. Photo of the materials sent away with each participant, including the waterproofed activPAL (attached to the leg) and a zipper bag containing three extra pieces of adhesive, instruction sheet, and sleep/non-wear diary

When the seven-day wear period was over, custom arrangements were made for me to collect the activPAL from the participant. In most cases, this collection occurred by me going to their homes or workplaces at a mutually convenient time, but in some cases, participants brought the device back to the hospital and left it with the research staff, posted it to me in an addressed pre-paid tracked envelope, or it was collected from participant homes by another member of the research team.

4.5.4 Glucose tolerance test (GTT)

The main outcome variable for this study was the result from each participant's glucose tolerance test (GTT), which usually took place between 24 and 28 weeks' gestation. The research team had no involvement in the GTT other than extracting the laboratory results from medical records. Both hospitals used 75g 2-hour GTT protocols, in which fasting blood samples were taken, a drink containing 75g of glucose was consumed, and a second blood sample was taken two hours after the drink was finished. Gestational diabetes was diagnosed at both hospitals if the fasting plasma glucose level was ≥5.6mmol/litre or if the 2-hour plasma glucose

level was ≥7.8mmol/litre, in accordance with NICE guidelines (National Institute for Health and Care Excellence, 2015). It should be noted that not all participants had the GTT; some went on home blood glucose monitoring instead early in their pregnancies because of previous GDM, some had contraindications (e.g., gastric bypass surgery) and could not have the test, and for others the reason is unknown. In these cases, glucose levels are not available; however, it was known if a participant developed GDM based on details provided in the antenatal records (based on, for example, diagnoses from home glucose monitoring or glycosuria detected in routine antenatal checks).

4.5.5 Other outcome variables

The results from the GTT, as well as data concerning the other outcome variables in this study (systolic and diastolic blood pressure in the third trimester, preterm delivery (delivery at <37 weeks' gestation), gestational age at birth, birthweight, and macrosomia (defined here as birthweight of ≥4000 grams)) were extracted from participants' antenatal medical records. These data were recorded on a study case report form (Appendix 8). Specific permission was given in the participant consent form for me (and the research team) to access these medical records. This data extraction took place on-site using the computers or medical notes in the offices of the research midwives. I was authorised to view this information because I had a research passport at both sites.

4.5.6 Questionnaires

Participants were asked to complete the Pregnancy Physical Activity Questionnaire (PPAQ, Appendix 3) a total of four times; however, the only questionnaire data that were ultimately used in this thesis were responses to questions concerning television time and occupational sitting time during the second trimester (to facilitate a more direct comparison with the activPAL data). The remaining three questionnaires were not used because changes in sitting time in these domains were not a focus of this thesis, and assessing changes in occupational sitting time would have been complicated by a lack of information concerning when/whether respondents in the third trimester had gone on maternity leave at the time they completed the questionnaire.

4.5.7 Semi-structured interviews

A subsample of participants (n=18) took part in a semi-structured interview. The main goal of the interview was to contextualise sedentary time and physical activity during pregnancy. More specifically, the interviews sought to identify factors that surrounded women's engagement in sedentary time and physical activity during pregnancy, such as their physical experiences, social interactions, and experiences of pregnancy overall. Secondary aims of the interviews included explorations of their interpretation of what it means to be 'at risk' for GDM and whether they modified their physical activity in response to learning of their 'risk'. Guide questions were selected to be very neutral and open-ended with the possibility of probing any responses which might be related to sedentary time, physical activity, or risk. The interview schedule is provided in Table 4.3.

Table 4.3. Semi-structured interview schedule

How would you describe what your pregnancy has been like so far?
In what ways have you found your lifestyle while pregnant has changed from your pre-pregnancy lifestyle?
Has there been anything about your experience during pregnancy that you didn't expect?
You were recruited to participate in this study because you had a risk factor for gestational diabetes. What does it mean to you to be 'at risk'? Were you diagnosed with gestational diabetes? Did knowing you were 'at risk' cause any changes in your lifestyle at all (regardless of diagnosis outcome)?
(For those diagnosed with gestational diabetes) Where did you get most of your information about what gestational diabetes is and how to manage it?

All participants were invited to be interviewed on the Participant Information Sheet, but only those who expressed interest in being interviewed on the study enrolment form were contacted when they were at 30 weeks' gestation. Not all interested participants were contacted; those who lived a substantial distance away and those who were recruited in the later stages of the study were not contacted. Interviews were conducted until 'information redundancy' was reached (i.e., when it was clear that no new information was emerging from the interviews) (Saunders et al., 2018). Interviews usually took place in participants' homes or cafes, but several (n=5) took place in private rooms in the hospital per the participant's request. In all but one case, I had recruited and/or fit the accelerometer to the participant, so some rapport had already been established prior to the interview.

Prior to beginning each interview, the participant signed a consent form specifically for the interview (Appendix 9). Each participant gave explicit permission for me to audio-record the interview using a digital voice recorder. Before the start of the interview, each participant was told that I was interested in what her experience of pregnancy was like. It was explicitly stated that I was not a health care professional nor an expert, and that there were no 'right' or 'wrong' answers to my questions. However, it is still acknowledged that my association with the hospitals and my identity as a physical activity researcher may have had some impact on how women interpreted my questions and responded to them (discussed further in Strengths and Limitations in Chapter Seven).

4.6 Regulatory issues

4.6.1 Ethical approval

Ethical approval was received from the Durham University Department of Anthropology on 2 March 2016. Following receipt of this approval, ethical approval was sought from the Research Ethics Committee (REC) within the NHS. Ethical approval was required from the NHS because recruitment and study activities were taking place within NHS premises. After revisions to the protocol, final ethical approval was granted from REC on 19 September 2016 (reference 16/SC/0355; Appendix 10). Following REC approval, approval is required from the Health Research Authority (HRA) and from each individual study site to confirm capacity to deliver the study before any study activities may begin. HRA approval was granted on 4 November 2016 (Appendix 11). Local Research and Development offices provided approval on 24 January 2017 and 30 January 2017 at the RVI and CHS, respectively (Appendix 12).

There were five main ethical issues associated with this study that were explicitly addressed in all ethics application forms. First, this study required access to medical records regarding pregnancy and childbirth in order to retrieve the outcome variables of interest. This required that I have the requisite credentials to be permitted to access such confidential information, and required that all extracted data be de-identified using alphanumeric pseudonyms in place of names and be stored on a secured institutional computer.

Second, the adhesive used to attach the activPAL to the skin has been known to cause skin irritation characterised by redness and itchiness. This has been reported in several studies that have used the activPAL in a 24-hour wear protocol (Edwardson et al., 2016b), and came up as an issue with three of six pilot participants before fieldwork began. To address this, all participants were informed both verbally and in writing on the instruction sheet they were given that they may experience skin irritation and, if that occurred, they should either move the device away from the irritated region or discontinue use altogether.

Third, as with any longitudinal studies during pregnancy, there was a possibility that participants could miscarry or experience an intrauterine death or other adverse outcome during the course of their pregnancy. It was therefore imperative that the study have a protocol for checking the viability of the pregnancy prior to each contact with the participant, and that this was strictly followed by everyone involved in the project.

Fourth, as semi-structured interviews were a component of the study, there was a possibility that participants may disclose information to me that indicated that they or their unborn babies may be at risk of harm (e.g., mentioning depression or describing depressed behaviour, not wanting the pregnancy, abusing drugs or alcohol). To address this, it was mentioned in the Participant Information Sheet and the consent form for the interview that if such information was disclosed, I would let their GP or midwife know.

Finally, the exact hypothesis of the study was not disclosed to participants at any point during the study. If participants were aware that sedentary time was the key focus of the study, it is likely that participants may become especially aware of their sedentary patterns and potentially alter them in a way that is not typical for them, which would compromise the integrity of the data. Therefore, participants were told that the study was looking at 'movement patterns' in relation to GDM risk without the true hypotheses being revealed.

Another key concern of the NHS ethical committees for all projects is that potential participants have sufficient time to be able to consider whether they would like to

take part in a study. This had implications for how the study was designed and how recruitment took place. In the final study design, participants were approached for the study and consented within the same day (after having a period of time at their scan appointment to read the information and consider participation); however, the ethics committee accepted this because although the turnaround for consenting was short, the study activities did not take place until eight weeks later, allowing that much time to reconsider participation in the main study activity.

4.6.2 Research passport

I held a research passport at both study sites following an occupational health check, DBS check, completion of Good Clinical Practice (GCP) training, and personal and professional references. My Letter of Access at CHS was issued on 13 July 2016, and was issued at the RVI on 14 February 2017. This Letter of Access permitted me to approach and consent participants and access medical records.

4.6.3 Data protection and confidentiality

The confidentiality of all participants taking part in this study was protected in accordance with the data protection guidelines of the NHS and Durham University. Computerised data files were maintained in an encrypted folder on a password-protected secure server at Durham University. One of these files contained personally identifiable information including participant names linked to assigned unique alphanumeric study ID numbers to allow identification of participants during the study, and contact details for correspondence related to the study. The file itself was password-protected for an extra layer of security and was destroyed at the end of the project. In all other data files, only study ID numbers were used. In all interviews, any information that could make the interviewee personally identifiable (e.g., names of partners or children) was redacted. All physical study materials with personally identifiable details (e.g., enrolment forms and questionnaires) were kept in locked cabinets within the research midwives' offices.

4.6.4 Funding

This study was funded by several sources. The Durham Doctoral Studentship funded my tuition fees and provided a living stipend for three years. The Biosocial Society provided a postgraduate fieldwork bursary (£750) which was used to fund

the costs of posting and collecting study materials. The Norman Richardson Travel Award via Ustinov College at Durham University provided funding (£1000) for the travel expenses associated with traveling between study sites. The Physical Activity Laboratory and the Department of Anthropology at Durham University funded equipment and consumable materials for this study.

4.6.5 Portfolio adoption

The project was adopted into the National Institute for Health Research Clinical Research Network Portfolio within the NHS on 2 December 2016 (CPMS ID 33200). Adoption into the portfolio provided access to research staff (e.g., research midwives, clinical trials assistants, and research midwives' office secretaries) at both study sites. The research staff provided support with identifying eligible participants, accessing participant appointment schedules and medical records, recruiting participants, fitting accelerometers, and administering questionnaires. For non-commercial studies such as this, the key eligibility criterion for portfolio adoption is the procurement of funding or equipment for the study that comes from a nationwide competition (i.e., not from a university), which I was able to secure through the grant awarded by the Biosocial Society and from a small donation of equipment from PAL Technologies, the manufacturer of the activPAL accelerometer used in this study.

4.7 Data processing

This section details how the enrolment forms, accelerometry files, questionnaires, outcome variables, and interviews were processed for the analyses presented in the results chapters.

4.7.1 Background demographic information

Data from the enrolment forms (Appendix 6) were extracted into an Excel spreadsheet linked to each participant's anonymous study ID.

Age was determined as the participant's age on the day of enrolment, based on the birthdate provided on the enrolment form.

BMI was classified in two ways. On the enrolment form, participants were asked to select their BMI in the two months before they knew they were pregnant from a range of options (<18.5, 18.5 to 24.9, 25 to 29.9, 30 to 39.9, more than 40), or provide their height and weight if they did not know their BMI. This self-reported BMI category was only used to compare the BMIs of those who withdrew from the study versus those who were retained, because the medical records of those who withdrew were not accessed. For those who did not withdraw from the study, the booking BMI (recorded by the midwife around 8 weeks' gestation) was extracted from medical records and was used in all models as a continuous variable.

Neighbourhood deprivation was determined by looking up the postcode provided on the enrolment form on the Index of Multiple Deprivation (IMD) database (2015). The IMD ranks the relative deprivation of each Lower Layer Super Output Area in England based on factors including income deprivation, employment deprivation, health deprivation, education deprivation, barriers to housing and services, and crime rate (ONS, 2009). Each small area is ranked from 1 (most deprived) to 32,844 (least deprived). Within health research, the IMD is traditionally used as deciles (Fairclough et al., 2017), quintiles (Stamatakis et al., 2014), or quartiles (Jones et al., 2009). However, this sample was disproportionately skewed toward more deprived areas, so using quintiles or quartiles resulted in very few representatives in the less-deprived groups; thus, tertiles were applied.

Participants who were in paid employment were asked to provide their job title. Their titles were assigned Standard Occupational Classification (SOC) 2010 Index codes, which are classified into nine occupational categories published by the Office for National Statistics (Office for National Statistics, 2010) (replacing the Registrar General's social class). The SOC 2010 occupational classifications, with examples of occupations included within each category, are shown in Table 4.4. Four job titles were not specific enough to be properly indexed; these were left blank.

Table 4.4. SOC 2010 occupational classification categories

SOC2010 occupational classification categories	Examples of occupations included
Managers, directors, and senior officials	CEOs, corporate managers, retail managers
Professional occupations	Health professionals, teachers, accountants
Associate professional and technical occupations	Paramedics, pharmaceutical technicians, laboratory technicians, marketing associate professionals
Administrative and secretarial occupations	Records clerks, book-keepers, medical secretaries, receptionists
Skilled trades	Farmers, mechanics, construction workers, cooks
Caring, leisure, and other service occupations	Nursery nurses, teaching assistants, nursing assistants, hairdressers, housekeepers
Sales and customer service occupations	Sales assistants, retail cashiers, customer service agents
Machine operatives	Large goods vehicle drivers, energy plant operatives, rail construction and maintenance operatives
Elementary occupations	Waiters and waitresses, security guards, cleaners, postal workers

The remaining demographic variables processed from the enrolment forms are shown below in Table 4.5. The column on the left shows the original response options on the enrolment form, along with the number of respondents (in the total recruited sample) for each category. The column on the right shows the way in which these categories were collapsed. In some cases (household income, employment status, previous GDM, and family history of diabetes), the categories were collapsed because there were so few representatives in some categories. In other cases (marital status, children at home, and smoking status during pregnancy), the categories were dichotomised because the information of interest was the effect of any versus none, not a graded or continuous effect. Previous full-term pregnancies ('parity') was coded in two ways. For results in Chapter 5 (where the study sample was described), parity was dichotomised as nulliparous or multiparous because the outcome of interest was how many nulliparous women were in the sample. In Chapter 6 results (focused on pregnancy outcomes), parity was coded as none, one, or two or more based on evidence suggesting that likelihood of obstetric complications may be highest in the first pregnancy, lowest in the second and third pregnancies, and begin to progressively increase from the fourth pregnancy onward (Bai et al., 2002).

Table 4.5. Original enrolment form variables (left column) and recoded variables (right column) for the entire study sample

Enrolment form variable	n per original category (total sample)	Recoded variable
Household annual income category		
<£20,000	128	Less than £20,000
Up to £40,000	108	£20-40,000
Up to £60,000	60	Above £40,000
Up to £100,000	13	
Above £100,000	0	
Missing	17	
Marital status		
Married	122	Married or cohabiting
Living with partner	139	
With partner, living apart	44	Single or living alone
Single, no partner	10	
Missing	10	
Previous full-term pregnancies ('parity')		
0	124	None
1	125	One
2	34	Two or more
3	25	
4 or more	11	
Missing	7	
Children at home		
0	118	None
1	130	Any
2	37	
3	23	
4 or more	12	
Missing	6	
Employment status		
Full time	151	Full time
Part time	89	Part time
Student	7	Not in paid work
Not in paid work	72	
Missing	6	
Smoking status during this pregnancy		
Yes, and still do	29	Any
Yes, but stopped	25	
Sometimes	15	
Not at all	249	None
Missing	8	
Previous GDM		
Yes	14	Yes
No	300	No
Not sure	4	
Missing	8	
Family history (parent or sibling) with Type 1 or Type 2 diabetes		
Yes	88	Yes
No	222	No
Not sure	9	
Missing	7	

4.7.2 Accelerometry

4.7.2.1 Downloading the data

Data from the activPALs were downloaded using the activPAL software created by PAL Technologies (version 7.2.32). As described in Chapter Three (section 3.3.2), proprietary algorithms within the software automatically classify posture and movement when the data are downloaded. The software generates several output files for each participant; the 'EventsXYZ'.csv file, which provides a chronological description of the order and duration of each bout of posture (sitting, standing, stepping) for each participant, was the key file used for the data processing.

4.7.2.2 Removing sleep and invalid data

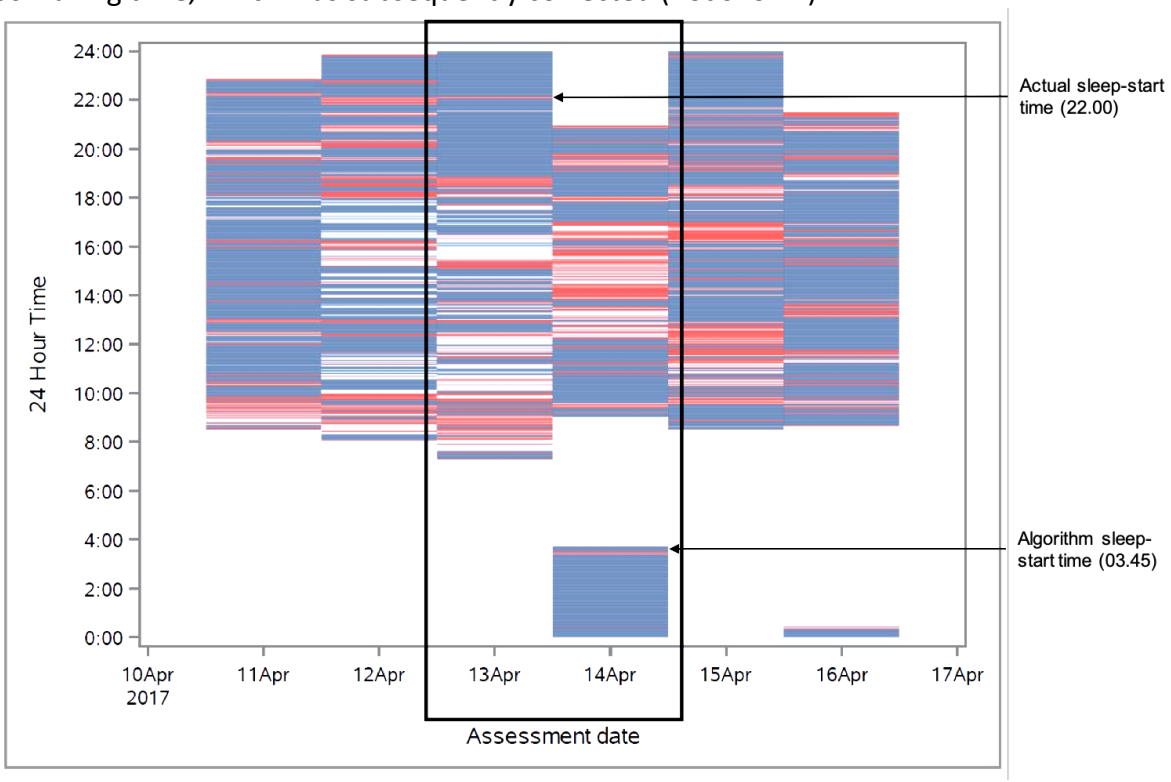
To remove any periods of invalid data and night-time sleep, each EventsXYZ file was processed in STATA using the validated algorithm developed by Winkler et al. (2016) as described in Chapter Three (section 3.5.3.1). The algorithm's default values for identifying sleep and prolonged non-wear were retained (refer to Figure 3.4).

After running the algorithm, each participant's data were visually checked using heat maps created in SAS to check that the algorithm was accurately identifying and removing invalid data and sleep. Upon initial inspection of the heat maps, it appeared that the algorithm's removals of sleep and non-wear were generally reasonable, suggesting that the thresholds applied in the algorithm were appropriate for this population. However, as is expected, there were some obvious misclassifications by the algorithm, most often to do with the algorithm classing interruptions in sleep time as the beginning of wake time (see Figure 4.4 for example). In all cases, participants' diaries were consulted (where available, n=182, 80% completion rate) to check their reported wake/sleep times and manual corrections were made to align the algorithm's classification with the diaries (refer to section 3.6.3.3 for protocol). An extra layer of precaution was taken to ensure that long bouts of sedentary time immediately before bed or upon waking (e.g., watching television before bed) were not incorrectly classified as sleeping time, and that trips to the toilet in the middle of the night were not incorrectly classified as the beginning of waking time. Each heat map was checked with participants' diaries to check that the algorithm-identified sleeping times were generally close to the diary times (i.e.,

difference of <1 hour); where these obviously conflicted, the algorithm times were adjusted to match the diaries.

In total, 183 sleep/wake times were manually corrected among 89 participants (for the remaining participants, no corrections were required). Thirty percent of the changes were reclassifications of sleep bouts to wake bouts; the remaining 70% of changes were reclassifications of wake bouts to sleep bouts. It is unclear how this proportion of manual corrections compares to other studies because this algorithm is too new to have been used by many studies, and such a level of detail has not been reported in studies that have used it. However, it is key to emphasise that this study used the algorithm as an *initial identifier* of where sleep and prolonged non-wear were likely to be occurring. Heat maps were extensively relied upon to visualise and understand the decisions the algorithm was making with each participant's data set, and the algorithm's decisions were corrected (and visualised again in a new heat map) where obvious misclassifications occurred. Thus, the number of manual corrections required is not necessarily a cause for concern because the data processing was ultimately informed by the diaries which were available in most cases.

Figure 4.4. Heat map indicating the algorithm's misidentification of the beginning of sleep time as 03.45 on 14 April instead of 22.00 on 13 April as indicated on the diary. It appears there were several interruptions in sleep during the night, which the algorithm misclassified as waking time, which was subsequently corrected (not shown).



4.7.2.3 Accelerometry outcome variables

After removing sleep and non-wear time, a separate algorithm (see section 3.5.3.4 in Chapter Three) was run in STATA to summarise the measurements produced by the proprietary software for each valid day. Days that represented days of fitting or removal of the activPAL were manually removed before calculating the main variables of interest: sedentary time, standing time, stepping time, sleeping time, waking wear time, prolonged sitting time, and breaks in sedentary time. Each of these variables were calculated as the sum of each valid day divided by the number of valid days. The same variables were extracted for each hour.

4.7.3 Questionnaires: television time and occupational sitting time

The questions concerning television time ('during your second trimester when you were not at work, how much time did you usually spend watching television or films?') and occupational sitting time ('during your second trimester, how much time did you usually spend sitting at work?') were extracted from the Pregnancy

Physical Activity Questionnaire. The response choices were the same for both questions: None, less than ½ hour per day, ½ to almost 2 hours per day, 2 to almost 4 hours per day, 4 to almost 6 hours per day, and 6 or more hours per day. These responses were dichotomised as less than 2 hours per day or at least 2 hours per day, with those not being in paid work (including students) classified as such.

It should be noted that the question about occupational sitting time was on the back side of the final page of the questionnaire, along with other questions about occupational physical activity. The questionnaire instructed participants to leave that page blank if they were not currently working or studying. An unforeseen consequence to this meant that it was impossible to distinguish whether the last page was intentionally left blank or just missed. To verify whether blanks were intentional, the participant's self-reported employment status (full-time, part-time, studying, not in paid work) from the enrolment form was consulted. If she reported being in paid work at enrolment and the second trimester response was blank (this occurred in 13 cases), the first trimester response to the occupational sitting question response was used. It is possible that this may have introduced some measurement error. It is unlikely that many women went on maternity leave by 20 weeks' gestation.

4.7.4 Outcome variables

Systolic and diastolic blood pressure readings in participants' antenatal notes were extracted. Because of the way in which blood pressure fluctuates across pregnancy (decreasing from first to second trimester, then increasing) in response to physiological changes including increases in total blood volume and cardiac output (Sanghavi and Rutherford, 2014), only blood pressure readings from the third trimester (after 30 weeks' gestation) were included. Participants had varying numbers of measurements during this period; the mean number of measurements was 3.8 (range 1 to 6), depending on how many antenatal visits they had. The average of all available readings was used as the outcome variable. Blood pressure readings were not available for 8 participants.

Gestational age at delivery and birthweight (in grams) were extracted from the delivery record. While some studies use a measure of birthweight standardised for gestational age and sex (e.g., Blell et al., 2008), raw birthweight was used here to

align with previous work that has tested the association between sedentary time and birthweight (Ruifrok et al., 2014). Gestational age at delivery was only used as an outcome for those who did not have a planned caesarean, since timing of delivery is likely to be determined by different factors in that group. Macrosomia was defined as birthweight ≥4000 grams (Reid et al., 2014, Hayes et al., 2014).

4.7.5 Interviews

All interviews were audio-recorded, transcribed verbatim, and proofread for accuracy. Interview transcripts were imported into NVivo and were inductively coded.

4.8 Statistical analysis

All statistical analyses were conducted using R. For all parametric tests, the data were checked to ensure the assumptions of parametric tests were met (primarily normal distribution of the data, homogeneity of variance, and lack of multicollinearity between predictor variables); these checks were made graphically (e.g., histograms and Q-Q plots) and using statistical tests (e.g., VIF and tolerance tests for multicollinearity). Chi-square analyses were only used where the minimum expected frequency for a cell (five) was satisfied.

While this study took place at two recruitment sites, multilevel models were not used because two sites (clusters) are too few to robustly estimate the random effects (Adetayo Kasim, personal communication). Thus, recruitment site is included as a control variable in all adjusted models.

Throughout the results, the R^2, adjusted R^2, and p-value for multiple linear regression models are provided under each table so that the fit of the model and the variance it explains can be interpreted. For multiple logistic regression models, the Akaike information criterion (AIC) is provided to interpret model fit (lower AIC values indicate lower data loss, thereby better model fit). In all multivariate models, the sample size included in that model is shown in the table title (which varies due to missing data points).

In all regression models, complete case analysis was used, such that participants with any missing data points relevant to each model were excluded. For this reason, the

sample size for participants with complete data (thus the n for each model) is provided in the title of each table.

A number of R packages were used in the statistical analyses, including *emmeans*, *compositions*, *car*, *sjstats*, *nlme*, *lme4*, *gmodels*, and *ggplot*.

4.8.1 Comparing characteristics between groups (withdrawn versus retained participants, those with valid versus invalid data sets, and by recruitment site)

Differences in continuous outcomes between groups were compared using independent samples t-tests. This included comparisons of age and BMI between those who did and those who did not provide valid accelerometry data sets, as well as comparisons of age, BMI, sedentary time (and other accelerometry variables), glucose levels, blood pressure, gestational ages at delivery, and birthweights between study sites.

Categorical variables were compared between groups using chi-square analyses. This included comparisons of BMI category and other categorical variables between those who withdrew and those who were retained, and comparisons of neighbourhood deprivation tertile, household income category, children at home, employment status and family history of diabetes between those who did and did not provide valid data sets, as well as between study sites among those who provided valid data.

4.8.2 Daily variation in sedentary time and stepping time

To assess how sedentary time and stepping time varied across days of the week, mixed models were used (to account for repeated measurements and the unbalanced number of weekdays and weekend days) with measurement day nested within participant (as the random effect), with day, waking time, and recruitment site included as fixed effects. From this, the estimated marginal means[26] of sedentary time or stepping time for each day were extracted. To test differences in sedentary time on weekdays versus weekend days, the same approach was used with 'day type' included instead of day as a fixed effect.

[26] Estimated marginal means describe the mean response for a given factor in a model, adjusted for the other covariates included in the model

A similar approach was used to assess how sedentary time varied by hour of the day: measurement hour was nested within participant (random effect), with hour and recruitment site included as fixed effects. Waking time was not controlled because only hours that had 60 minutes of waking wear were included. Estimated marginal means were used to provide hourly estimates of sitting time.

4.8.3 Seasonal variation in sedentary time and television time

To assess whether sedentary time varied by season (to know if season should be controlled in subsequent models), a simple linear regression model was used with season (defined as spring (March to May), summer (June to August), and autumn (September to November)) predicting total sedentary time. Number of daylight hours[27] during the week of wear was also examined as a predictor of total sedentary time.

Season and daylight hours were also used to test whether prolonged television time (≥2 hours per day) in the second trimester varied by time of year using simple logistic regression models. The same measures of season and day length were used in this model as the total sedentary time model described above.

4.8.4 Predictors of sedentary time and stepping time

Simple linear regressions between each potential predictor variable and sedentary time or stepping time were run to assess the independent associations between each predictor variable. For these models, the regression coefficients (*b*) with 95% confidence intervals are provided. Since stepping time was positively skewed, log-transformed stepping time (which produced a normal distribution) was the outcome variable in the model.

Multiple linear regression (forced entry) was then used to assess the associations of various independent variables with sedentary time and stepping time. For these models, the standardised regression coefficient (β) with 95% confidence intervals is provided to allow interpretation of the relative effect size of each variable included

[27] Daylength was retrieved from https://www.timeanddate.com/sun/uk/newcastle-upon-tyne for the day the accelerometer was fit

in the model. Estimated marginal means were used to calculate the differences in mean sedentary time between groups.

4.8.5 Testing associations between objectively measured sedentary time and sedentary behaviours

To assess whether television time (dichotomised as less than or at least 2 hours per day) or occupational sitting time (less than or at least 2 hours per day or not in paid work) were associated with total sedentary time or prolonged sedentary time (sedentary time accumulated in bouts lasting ≥30 minutes), simple linear regression was used with the sedentary behaviour (e.g., television time) predicting objectively measured sedentary time. Simple Poisson regression was used in the same way to predict breaks in sedentary time (which are effectively counts).

4.8.6 Testing 'traditional' associations between sedentary time/behaviour and binary pregnancy outcomes (gestational diabetes, preterm delivery, macrosomia)

Associations between total sedentary time, prolonged sedentary time, and breaks in sedentary time with binary pregnancy outcomes (GDM and macrosomia) were tested using logistic regression. Age, recruitment site, waking time, and stepping time were controlled in all accelerometry models. Models testing the effects of breaks in sedentary time additionally controlled for total sedentary time. In all models in which television time or occupational sitting time were predictor variables, age, recruitment site, and stepping time were controlled. Additional relevant control variables for each outcome were included if their univariate associations with the outcome variables in simple logistic regression models were significant.

4.8.7 Testing 'traditional' associations between sedentary time/behaviour and continuous pregnancy outcomes (glucose levels, blood pressure, gestational age at delivery, birthweight)

Associations between total sedentary time, prolonged sedentary time, and breaks in sedentary time with continuous pregnancy outcomes (fasting and 2-hour glucose levels, systolic and diastolic blood pressure, gestational age at delivery, birthweight) were tested using linear regression. Fasting and 2-hour glucose levels were

positively skewed and were thus log-transformed, which resulted in a normal distribution.

Because GDM is a pathological condition and the glucose levels of those with GDM may be affected differently than those without GDM, interaction terms between GDM status and centred accelerometry variables were applied to models in which glucose levels were the outcome. If the interaction was significant ($p<0.05$), estimated marginal means of linear trends were applied to the model. These are comparable to estimated marginal means, but provide the regression coefficient with confidence intervals for the predictor and outcome separately by a grouping factor (in this case, GDM diagnosis). No p-values are presented because significance tests for estimated marginal means of linear trends are only used for pair-wise comparisons; thus, significance is determined by confidence intervals that do not cross zero.

As with the previous section, all accelerometry models controlled for age, recruitment site, waking time, and stepping time; all television and occupational sitting models controlled for age, recruitment site, and stepping time. Models testing the effects of breaks in sedentary time additionally controlled for total sedentary time. Additional relevant control variables for each outcome were included if their univariate associations with the outcome variables in simple linear regression models were significant.

4.8.8 Compositional models

Compositional models, which have only recently been applied to physical activity research, were used to test associations between 24-hour time use (i.e., time allocated to sitting, standing, stepping, and sleeping) and each outcome variable, either within a logistic regression model (binary outcomes) or linear regression model (continuous outcomes) in the same way as described above. Compositional models were run using the R-package *Compositions* (version 1.40-2). The key advantage offered by using compositional models is the ability to account for the way in which time allocated to sitting, standing, stepping, and sleeping are collectively linked to outcome variables, without introducing collinearity. If the composition as a whole significantly predicts the outcome, predictive modelling can be used to model

hypothetical reallocations of time spent in one component (e.g., sedentary time) to time spent in another (e.g., stepping).

First, the compositional mean of the four accelerometry components was calculated for each participant by using the acomp function in the *Compositions* package. The result of this is a construction of a true composition, wherein all the sum of time spent in each component is converted to a proportion that will add up to 1 (note that because accelerometry was used over a 24-hour period, this transformation is simply a normalisation to remove rounding errors and smooth day-to-day variation in the data).

Next, an isometric log-ratio transformation was applied to the composition, which allows the relative positions of the data points to be preserved in the transformation from the simplex to the real space (Chastin et al., 2015b, Dumuid et al., 2017). For a four-part composition (as was used in this study), four sets of ilr coordinates are created – one with each variable as the numerator (I called my coordinate systems *compSleep, compSed, compStand*, and *compStep*) with the remaining three variables account for in the ratio. The ordering of the variables does not matter, so long as they are consistent.

To use the compositional data in regression models, four separate regression models were run, each with the different sets of ilr coordinates entered into the model (e.g., a model for *compSleep,* a model for *compSed*, etc.). It should be noted that the R^2 for each model is identical for each of the four models, as are the regression coefficients and p-values for all other covariates included in the model. To interpret the model, the first coefficient (γ) represents the effect of that component on the outcome relative to time spent in the others (i.e., not 'independently' of the others). Then three more regression models, using the three remaining sets of ilr-coordinates, are run with the first coefficient of each extracted.

In the results of the compositional models, one table is shown but it is the result of four separate models (all with the same R^2 values and coefficients for control variables).

To test whether the composition as a whole significantly predicts the outcome, ANOVA is run on the model predictors; if the composition as a whole is significant ($p<0.05$), predictive substitution modelling can be done to test the impact of reallocating time spent between components. However, the composition was not significantly associated with any outcomes in this thesis, so this was not done and is thus not detailed here.

4.9 Qualitative analysis

Interview transcripts were coded using NVivo, modelled after the guidance provided by King and Horrocks (2010). Given the unstructured nature of the interviews (and thus the discussion of a wide variety of topics during the interview that were not directly relevant to the questions at hand), sections within each transcript that were related to sedentary time, physical activity, or gestational diabetes were given an initial deductive code ('sedentary time,' 'physical activity,' or 'gestational diabetes'). Within each broad code, inductive descriptive codes were assigned to each line to capture its essence or meaning. In this particular data set, these codes tended to concern contextual details of, for example, sitting time (e.g., being told to sit by [person], where or why, personal response). Descriptive codes that shared common meanings were grouped together into interpretive codes; the original data were revisited to ensure the interpretive codes were accurate representations. The interpretative codes were subsequently organised into overarching themes, and again, the original data were revisited to ensure the themes reflected the underlying data.

I conducted all of the analyses on my own. I recognise that my own subjectivity determined the way in which I interpreted the data, which in turn influenced each step of the coding process. The quality of the analyses would have been strengthened by the use of independent coding, which could have helped to highlight where I may have missed alternative interpretations of the data due to my own assumptions or expectations (King and Horrocks, 2010). This is discussed further in the Strengths and Limitations of Chapter 7 (pages 210-212).

Chapter Five: Prevalence, patterns, and predictors of sedentary time and sedentary behaviours during the second trimester among pregnant women with a risk factor for gestational diabetes

5.1 Aims

Based on the rationale laid out in Chapter Two (sections 2.5 and 2.6), this chapter describes the sample population in this study and reports their patterns of objectively measured sedentary time (as well as time spent standing, stepping, and sleeping) during the second trimester as measured by the activPAL. Although sedentary time is the focus of this thesis, descriptive statistics of standing and sleeping are presented because they are included in the compositional models in Chapter 6, and sociodemographic predictors of stepping time are presented because stepping is included as a control variable in all 'traditional' models in Chapter 6. The prevalence and predictors of television time and occupational sitting time, as well as their associations with activPAL-measured total sedentary time, are also presented.

5.2 Research questions

This chapter aims to address the following research questions:

1. What is the mean total sedentary time in this sample?
2. How is sedentary time patterned across the week (daily) and across the day (hourly)?
3. What sociodemographic factors are associated with total sedentary time?
4. What proportion of the sample watches television for at least two hours per day, and what sociodemographic factors are associated with higher television time?
5. What proportion of the sample sits at work for at least two hours per day, and what sociodemographic factors are associated with higher occupational sitting time?
6. What is the strength of the association between total sedentary time and television time or sitting at work?

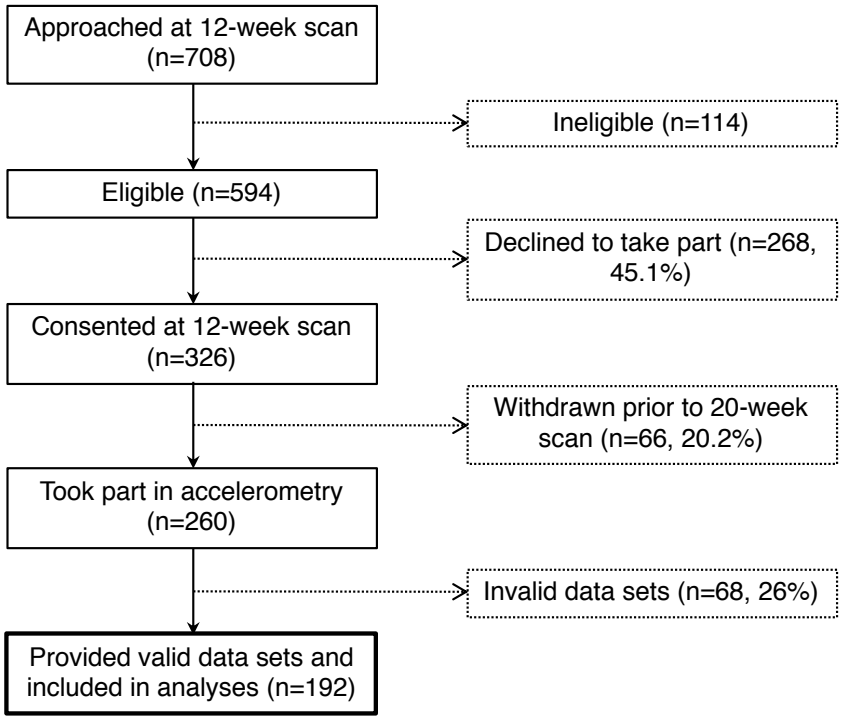
5.3 Results

5.3.1 Description of the study sample

5.3.1.1 Recruitment and response rate

The flow chart illustrating the recruitment process is shown in Figure 5.1. It is estimated that 708 potentially eligible women were approached to take part in the study (369 and 339 at the RVI and CHS, respectively)[28]. Of these, 114 turned out to be ineligible (e.g., did not have a viable pregnancy at their dating scan, did not speak English fluently, or did not actually have a risk factor for GDM) and were therefore not consented to the study. Out of the remaining eligible participants (n=594), 326 consented to take part in this study, thus the overall response rate was 54.9%. The local response rates are estimated to be 47.2% and 62.0% at the RVI and CHS, respectively.

Figure 5.1. Flow chart of the recruitment process.



[28] Recruitment logs were kept at both sites to detail who was approached and who was consented to monitor response rate. However, not every person recruiting always remembered to record who they approached, thus these figures may be underestimations.

5.3.1.2 Comparison of characteristics between those who withdrew and those who did not

Of the 326 women who were enrolled in the study, 66 (20.2%) withdrew from the study and did not wear the activPAL. The majority (n=46, 69.7%) of withdrawals were due to participants simply saying they did not wish to continue in the study. In the remainder of cases, participants were administratively withdrawn upon confirmed foetal abnormality or miscarriage (n=10, 15.1%), or inability to contact the participant[29] (n=10, 15.1%).

Descriptive statistics for all who consented to the study ('total sample') are shown in Table 5.1. Some data points are missing due to incomplete or missing enrolment forms; the number of available data points for each variable is reported in the table. Overall, the majority of those who consented to the study were obese (self-reported BMI≥30kg/m^2), lived in the most deprived neighbourhoods (based on Index of Multiple Deprivation (IMD) tertile), were employed or studying, and had experienced at least one previous full-term pregnancy.

Table 5.1 shows the results from statistical comparisons between those who withdrew from the study and those who did not. Those who withdrew from the study were significantly younger than those who agreed to wear the accelerometer (p=0.03). Additionally, a relatively larger proportion of withdrawn participants had lower educational qualifications, although this did not reach significance (p=0.08). There were no significant differences in BMI category, neighbourhood deprivation, household income category, work status, or parity (Table 5.1).

[29] For example, one participant felt very ill at her anomaly scan and did not want to have her accelerometer at that particular time, but was happy to be contacted the following week to set up a fitting. After three attempts to contact her with no response, the participant was administratively withdrawn.

Table 5.1. Description of the recruited population ('total sample'), with comparisons of characteristics between those who withdrew from the study prior to wearing the activPAL and those who wore the device based on independent t-tests (age) and chi-square analyses (all categorical variables). Significant values (p<0.05) are bolded.

Characteristic	Total sample (n=326)	Retained (n=260)	Withdrawn (n=66)	p-value
Age (n=326) Mean (SD)	29.9 (5.3)	30.2 (5.3)	28.6 (5.2)	**0.03**
BMI category* (n=306)				0.66
Less than 29.9	31 (10.1%)	24 (9.6%)	7 (12.5%)	
30.0 – 39.9	227 (74.2%)	185 (74.0%)	42 (75.0%)	
40.0 or higher	48 (15.7%)	41 (16.4%)	7 (12.5%)	
Neighbourhood deprivation (n=317)				0.90
Most deprived	205 (64.7%)	168 (64.9%)	37 (63.8%)	
Middle	58 (18.3%)	48 (18.5%)	10 (17.2%)	
Least deprived	54 (17.0%)	43 (16.6%)	11 (18.0%)	
Income category (n=309)				0.49
Less than £20,000	128 (41.4%)	100 (40.0%)	28 (47.5%)	
Between £20-40,000	108 (35.0%)	88 (35.2%)	20 (33.9%)	
Above £40,000	73 (26.6%)	62 (24.8%)	11 (18.6%)	
Work status (n=320)				0.19
In paid work	241 (75.3%)	199 (76.8%)	42 (68.9%)	
Not in paid work^	79 (24.7%)	60 (23.2%)	19 (31.1%)	
Highest education (n=316)				0.08
GCSEs or below	159 (50.3%)	120 (46.9%)	39 (65.0%)	
A-levels	42 (13.3%)	35 (13.7%)	7 (11.7%)	
University/postgrad	85 (26.9%)	75 (29.3%)	10 (16.7%)	
Other qualification	30 (9.5%)	26 (10.2%)	4 (6.7%)	
Parity (n=324)				0.54
Nulliparous	129 (39.8%)	101 (39.0%)	28 (43.1%)	
Multiparous	195 (60.2%)	158 (61.0%)	37 (56.9%)	

* Based on self-reported BMI category because the medical records of withdrawn participants were not accessed

^ Includes students

IQR: interquartile range

5.3.1.3 Characteristics of the final accelerometry study sample

In total, 260 women participated in wearing the activPAL accelerometer. Sixty-eight (26%) of these participants did not provide enough data to meet the minimum wear criteria (at least four full days of wear) and were thus excluded from analyses. A substantial proportion of 'insufficient wear' was attributed to skin reactions to the accelerometer and/or the dressing with which it was attached; 50 participants explicitly stated either to me or on their wear diary that they experienced at least some degree of skin irritation underneath the device, and in at least 21 of these cases, the device was removed prematurely due to the severity of the skin irritation. Additionally, sixteen activPALs stopped recording prematurely, usually due to the battery dying despite being fully charged at initialisation.

One hundred and ninety-two women met the minimum wear criteria of at least 10 hours of wear on at least four days. Within this sample, 133 (69%) provided six or more days of valid wear, and 190 (99%) had at least one valid weekend day. Descriptive statistics of the final study sample (n=192) are provided in Table 5.2, along with statistical comparisons of participant characteristics between the two study sites.

Study sites differed significantly in BMI, neighbourhood deprivation, parity, and family history of diabetes (Table 5.2). Compared to the RVI, participants from CHS had significantly higher BMIs ($p<0.001$), and larger proportions of CHS participants resided in neighbourhoods with higher deprivation ($p<0.001$) and were nulliparous ($p=0.04$). In contrast, a larger proportion of participants at the RVI reported a family history of diabetes compared to CHS ($p<0.001$). This difference may reflect differences in recruitment strategies between the two study sites (CHS tended to recruit based on BMI while the RVI tended to recruit more liberally based on any eligibility criterion, one of which was family history of diabetes) or differences in the types of patients who attend each hospital (the RVI tends to manage 'higher-risk' cases referred from beyond the catchment area compared to CHS). No significant differences between study sites were found in age, income category, number of children at home, working status (working versus not), or smoking status during

pregnancy; differences in highest educational attainment approached but did not reach significance (p=0.09; Table 5.2).

Proportional differences in ethnicity and previous GDM incidence could not be statistically compared between study sites because the minimum expected frequencies were too low to satisfy the assumptions of chi-square analysis, so these are briefly described here. At CHS, 96.3% of the sample was White British, compared to 94% of the sample at the RVI. Three women from CHS (2.8% of CHS sample) had previously had GDM, compared to 6 cases (7.1% of RVI sample) at the RVI. All accelerometry-based results presented in the remainder of this thesis are based on these 192 participants.

Table 5.2. Description of the total valid accelerometry sample and comparison of characteristics between the two study sites using independent t-tests (age and BMI) and chi-square analyses (categorical variables). Significant (p<0.05) p-values are bolded.

Characteristic	Total (n=192)	CHS (n=108)	RVI (n=84)	p-value
Age (n=192)				0.12
Mean (SD)	31.1 (5.1)	30.6 (5.21)	31.7 (4.95)	
BMI (n=184)				**<0.001**
Mean (SD)	34.7 (5.6)	36.3 (5.3)	32.4 (5.4)	
Neighbourhood deprivation (n=191)				**<0.001**
Most deprived	119 (62.3%)	80 (74.1%)	39 (47.0%)	
Middle	36 (18.8%)	14 (13.0%)	22 (26.5%)	
Least deprived	36 (18.8%)	14 (13.0%)	22 (26.5%)	
Income category (n=185)				0.57
Less than £20,000	62 (33.5%)	35 (34.0%)	27 (32.9%)	
£20-40,000	69 (37.3%)	41 (39.8%)	28 (34.1%)	
≥£40,000	54 (29.2%)	27 (26.2%)	27 (32.9%)	
Parity (n=191)				**0.04**
Nulliparous	73 (38.2%)	48 (44.4%)	25 (30.1%)	
Multiparous	118 (61.8%)	60 (55.6%)	58 (69.9%)	
Number of children at home (n=191)				0.18
None	70 (36.6%)	44 (40.7%)	26 (31.3%)	
One or more	121 (63.4%)	64 (59.3%)	57 (68.7%)	
Education (n=189)				0.09
GCSEs or below	81 (42.9%)	51 (48.1%)	30 (36.1%)	
A-levels	26 (13.8%)	9 (8.5%)	17 (20.5%)	
University/postgraduate	61 (32.3%)	35 (33.0%)	26 (31.3%)	
Other qualification	21 (11.1%)	11 (10.4%)	10 (12.1%)	
Working status* (n=191)				0.21
Full time	101 (52.9%)	55 (50.9%)	46 (55.4%)	
Part time	54 (28.3%)	28 (25.9%)	26 (31.3%)	
Not in paid work	36 (18.8%)	25 (23.1%)	11 (13.3%)	
Marital status (n=191)				0.95
Married/cohabiting	166 (86.9%)	94 (87.0%)	72 (86.7%)	
Single or living apart	25 (13.1%)	14 (13.0%)	11 (13.3%)	
Smoking status during pregnancy (n=191)				0.44
None	154 (80.6%)	85 (78.7%)	69 (83.1%)	
Some/regularly	37 (19.4%)	23 (21.3%)	14 (16.9%)	
Family history of diabetes (n=191)				**<0.001**
Yes	58 (30.4%)	22 (20.4%)	36 (43.4%)	
No	133 (69.6%)	86 (79.6%)	47 (56.6%)	

* Working status reflects what was reported at the time of enrolment (at 12 weeks' gestation)

5.3.2 Descriptive statistics of sedentary and stepping time

5.3.2.1 Mean sedentary and stepping time with comparisons between study sites

Descriptive statistics of sedentary time, stepping time, and waking time from valid data sets as measured by the activPAL (n=192) are reported in Table 5.3. The outcome variables in all analyses were means for each participant, defined as the sum of hours on valid days divided by the number of valid days, with the days of fitting and removal excluded. Due to a positive skew, both stepping and standing time were log-transformed (no values were zero). No significant differences in sedentary time, prolonged sedentary time, stepping time, standing time, waking time, or sleep time were found between study sites (Table 5.3). Breaks in sedentary time were significantly higher among RVI participants compared to CHS (p=0.04).

Table 5.3. Descriptive statistics of sedentary time and other accelerometry variables for all valid data sets and compared between both study sites using independent t-tests.

Variable (hours)	**Total** (n=192) Mean (SD)	**CHS** (n=109) Mean (95%CI)	**RVI** (n=83) Mean (95%CI)	**p-value**
Sedentary time	9.57 (1.62)	9.46 (9.14, 9.78)	9.71 (9.37, 10.05)	0.28
Prolonged sedentary time	2.38 (0.83)	2.33 (2.17, 2.49)	2.44 (2.26, 2.62)	0.38
Breaks in sedentary time	52.8 (13.7)	50.7 (48.4, 53.0)	54.0 (51.6, 58.4)	**0.04**
Stepping time*	1.42 (0.53)	1.42 (1.32, 1.52)	1.40 (1.28, 1.52)	0.86
Standing time*	3.32 (0.37)	3.29 (2.99, 3.56)	3.35 (3.09, 3.61)	0.80
Waking time	14.68 (1.04)	14.64 (14.44, 14.84)	14.73 (14.50, 14.96)	0.52
Sleep time	9.32 (1.04)	9.36 (9.16, 9.56)	9.27 (9.04, 9.50)	0.57

* t-test performed on log-transformed values due to positive skew; back-transformed means presented here

Because night-time sleep time detected by the algorithm (9.32 hours, reported in Table 5.3) seemed high, the algorithm's classification of sleep time was compared against self-reported sleep time from participants' diaries for verification. Among the completed sleep diaries provided by participants included in the accelerometry data set (n=169, 88% of valid data sets), mean reported sleep duration was 9.1 hours per night (range 7.1-13.0 hours). The intra-class correlation coefficient comparing self-reported sleep time and algorithm sleep time for the entire sample was 0.65 (95%CI 0.53, 0.46, p<0.001), indicating good but not excellent agreement between the

two measures of sleep. However, in the diaries, sleep start and end times appeared to be estimates as they were usually reported to the nearest half-hour. Since the algorithm has been validated for the detection of sleep (Winkler et al., 2016) and the agreement between the algorithm and the diaries was generally good, the algorithm-derived sleep time reported here seems reasonable.

Dividing the mean sedentary time by the mean waking time (as shown in Table 5.3) indicates that 65.2% of waking time was spent sedentary, 9.7% was spent stepping, and 22.6% spent standing.

5.3.2.2 Daily variation in sedentary and stepping time

To assess the variation in sedentary time and stepping time across days of the week, mixed models with measurement day nested within participant were constructed with adjustment for waking time and recruitment site.

The estimated marginal means, plotted in Figures 5.2 and 5.3, indicate that Sunday has both the highest sedentary time and the lowest stepping time. Sedentary time did not significantly differ by days of the week ($p=0.09$), nor did weekdays significantly differ from weekend days ($p=0.07$).

Figure 5.2. Estimated marginal means of sedentary time on each day of the week. Error bars represent 95% confidence intervals. The dotted line represents the grand mean for all days.

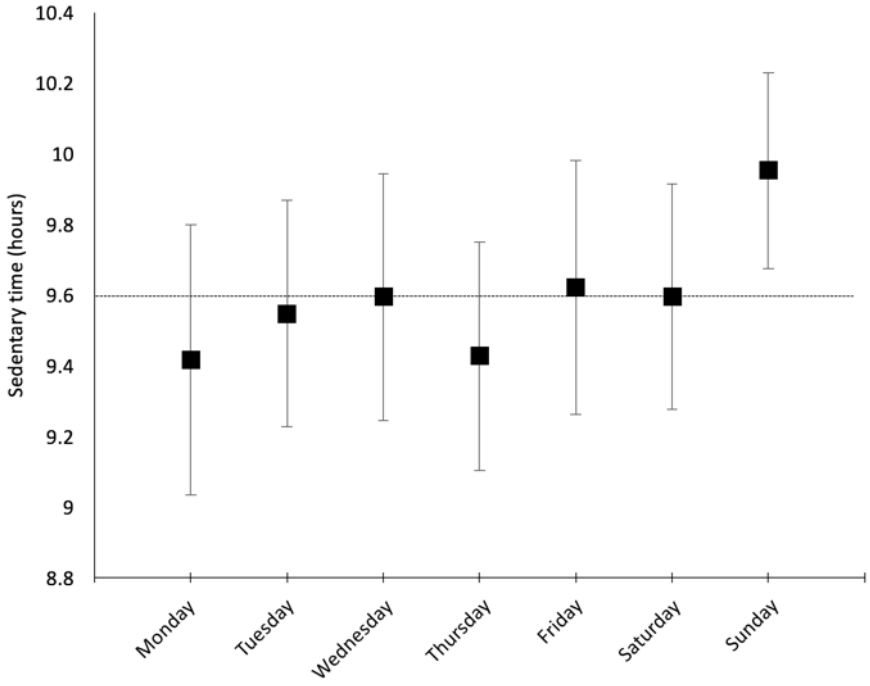
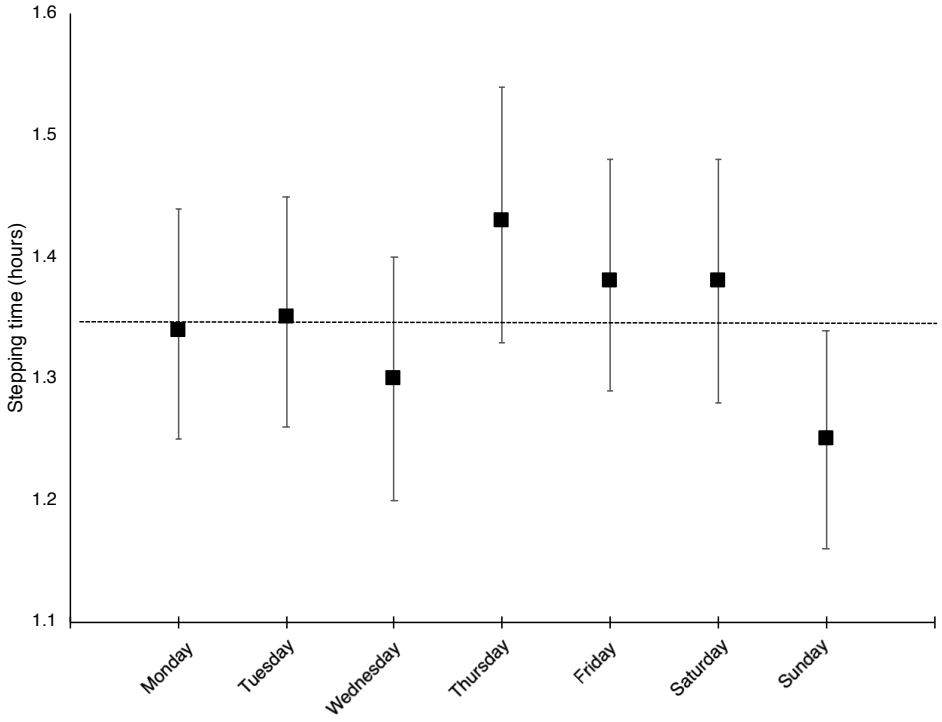


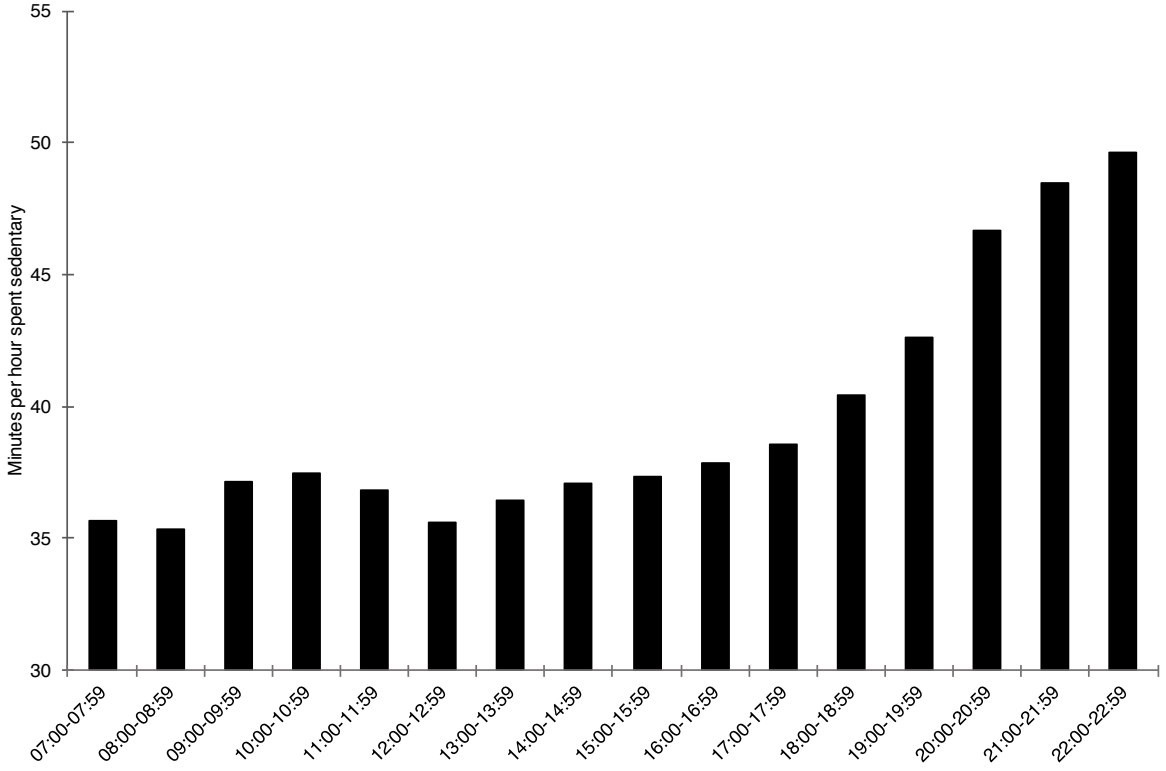
Figure 5.3. Estimated marginal means of stepping time on each day of the week. Error bars represent 95% confidence intervals. The dotted line represents the grand mean for all days.



5.3.2.3 Hourly variation in sedentary time

Hourly variation in sedentary time could not be analysed statistically because many hours featured all or no sedentary time (i.e., zero sedentary time or all sedentary time) that could not be forced into a normal distribution. Therefore, the data (which are from mixed models in which hours were nested within participants) are presented only as graphs. Only hours with 60 minutes of waking time were included. The hours on all valid days are shown here together because separate analyses of hourly sedentary time on weekdays, Saturday, and Sunday did not produce different patterns (data not shown). The results, shown in Figure 5.4, indicate that the hours with the highest sedentary time for the whole sample on all days occurs after 6pm, with 8pm to 11pm having substantially higher sedentary time (>45 minutes per hour).

Figure 5.4. Hourly sedentary time (minutes sedentary per complete hour of waking wear) for all participants (n=192)



5.3.2.4 Seasonal variation in sedentary time

Sedentary time did not significantly differ among participants who wore the activPAL in the spring (March to May), summer (June to August), or autumn (September to November) (Table 5.4). Number of daylight hours during the week of wear was also not associated with sedentary time (p=0.90).

Table 5.4. Estimated marginal means of sedentary time by season of wear.

	Spring (n=54)	Summer (n=94)	Autumn (n=44)	p-value
Sedentary time *Mean (95%CI)*	9.5 (9.0, 9.9)	9.6 (9.3, 10.0)	9.6 (9.1, 10.0)	0.82

5.3.2.4 Summary

In summary, the majority of waking hours (65.2%) in this sample were spent sedentary. While sedentary time remained relatively stable across the days of the week, Sunday had the highest sedentary time. Furthermore, hourly sedentary time was the highest in the evenings, particularly after 8pm. These findings are the first of their kind among a pregnant population, and attest to the importance of measuring sedentary time using a 24-hour protocol on multiple days to capture the within-individual patterns of sedentary time across the day and the week.

5.3.3 Predictors of mean sedentary and stepping time

5.3.3.1 Predictors of overall mean sedentary time

Simple linear regression models, shown in Table 5.5, indicate that BMI and neighbourhood deprivation are significant univariate predictors of sedentary time; income category (above £40,000) approached significance (p=0.06). These variables, along with age, children at home, marital status, employment status, smoking status (based on the association reported by Evenson and Wen (2011)) and recruitment site were thus included in the multiple regression models.

Table 5.5. Univariate predictors of sedentary time in minutes using simple linear regression. Significant (p<0.05) values are bolded.

Predictor variable	***b* (95%CI)**	**p-value**
BMI	-2.62 (-5.13, -0.10)	**0.04**
Age	-1.07 (-3.79, 1.64)	0.44
Neighbourhood deprivation		
Most deprived (referent)		
Middle	58.70 (22.94, 94.45)	**<0.01**
Least deprived	31.61 (-4.15, 67.37)	0.08
Income category		
<£20,0000 (referent)		
£20-40,000	0.81 (-32.32, 33.95)	0.96
≥£40,000	33.19 (-2.05, 68.44)	0.06
Number of children at home		
None (referent)		
Any	10.11 (-18.55, 38.77)	0.49
Marital status		
Married or cohabiting (referent)		
Single or living alone	24.63 (-16.21, 65.47)	0.24
Employment status		
Full time (referent)		
Part time	-1.33 (-38.45, 35.78)	0.94
Not in paid work	13.46 (-18.77, 45.70)	0.41
Smoking status during pregnancy		
None (referent)		
Any	11.00 (-23.95, 45.96)	0.54
Recruitment site	15.39 (-12.58, 43.37)	0.28

The results of the multivariate regression model shown in Table 5.6 indicate that age, neighbourhood deprivation, and income category were significantly associated with sedentary time. The strongest predictor (as indicated by the β value) of sedentary time was income; those who reported a household income of at least £40,000 per year had significantly higher sedentary time than those with an income of less than £20,000 (β=0.30 (95%CI 0.10, 0.50)). Age and sedentary time were inversely related such that as age goes up, sedentary time goes down (β=-0.18 (95%CI -0.33, -0.02)). The middle neighbourhood deprivation tertile had significantly higher sedentary time than the most deprived tertile (β=0.16 (95%CI 0.01, 0.30)), but the least deprived tertile was not significantly different (β=0.08 (95%CI -0.07, 0.23)). BMI, children at home, marital status, employment status, smoking status during pregnancy, and

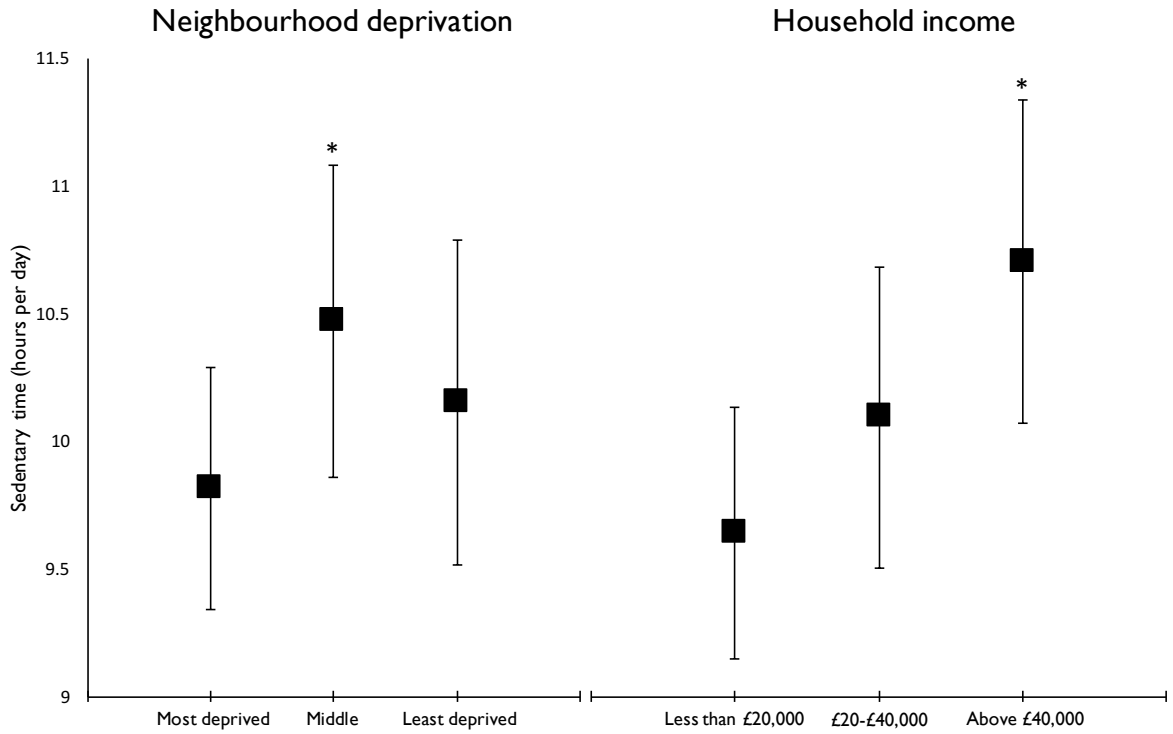
recruitment site did not significantly predict sedentary time (Table 5.6). Estimated marginal means from the model in Table 5.6 are plotted in Figure 5.5.

Table 5.6. Multiple linear regression results of predictors of sedentary time in minutes. Significant values (p<0.05) are bolded (n=180).

Predictor variable	**β (95%CI)**	**p-value**
Age	-0.18 (-0.33, -0.02)	**0.03**
BMI	-0.11 (-0.26, 0.03)	0.14
Neighbourhood deprivation		
Most deprived (referent)		
Middle	0.16 (0.01, 0.30)	**0.04**
Least deprived	0.08 (-0.07, 0.23)	0.29
Income category		
<£20,000 (referent)		
£20-40,000	0.14 (-0.06, 0.33)	0.17
≥£40,000	0.30 (0.10, 0.50)	**0.004**
Number of children at home		
None (referent)		
Any	0.03 (-0.12, 0.19)	0.66
Marital status		
Married or cohabiting (referent)		
Single or living alone	0.14 (-0.02, 0.31)	0.08
Employment status		
Full time (referent)		
Part time	0.08 (-0.08, 0.24)	0.32
Not in paid work	0.10 (-0.08, 0.27)	0.27
Smoking status during pregnancy		
None (referent)		
Any	0.06 (-0.08, 0.20)	0.42
Recruitment site	0.01 (-0.14, 0.16)	0.94
Waking time	0.31 (0.16, 0.45)	**<0.001**

R^2=0.21, adjusted R^2=0.15, p<0.001

Figure 5.5. Estimated marginal means of sedentary time by neighbourhood deprivation tertile (left) and by household income category (right). Asterisks denote significant differences (as shown in the model in Table 5.6) with the referent groups (most deprived and lowest income, respectively).



5.3.3.2 Predictors of overall mean stepping time

As with sedentary time, the same univariate predictors of stepping time were tested using simple linear regressions to determine what factors need to go into the multivariate model. Stepping time was positively skewed (no values were zero), so it was log-transformed to a normal distribution. Results of the simple regression analyses, shown in Table 5.7, indicate those in the least deprived neighbourhoods had significantly lower stepping time than those in the most deprived neighbourhoods.

Table 5.7. Simple linear regression results of sociodemographic variables predicting mean stepping time (log transformed). Significant values (p<0.05) are bolded.

Predictor variable	***b* (95%CI)**	**p-value**
Age	-0.004 (-0.02, 0.01)	0.58
BMI	0.002 (-0.010, 0.015)	0.72
Neighbourhood deprivation		
Most deprived (referent)		
Middle	0.05 (-0.13, 0.23)	0.61
Least deprived	-0.20 (-0.38, -0.02)	**0.03**
Income category		
<£20,000 (referent)		
£20-40,000	0.01 (-0.16, 0.18)	0.87
≥£40,000	-0.04 (-0.22, 0.14)	0.67
Number of children at home		
None (referent)		
Any	-0.02 (-0.16, 0.13)	0.83
Marital status		
Married or cohabiting (referent)		
Single or living alone	0.14 (-0.07, 0.34)	0.20
Employment status		
Full time (referent)		
Part time	0.08 (-0.08, 0.25)	0.32
Not in paid work	-0.02 (-0.20, 0.17)	0.86
Smoking status during pregnancy		
Any smoking (referent)		
None	-0.02 (-0.20, 0.16)	0.83
Recruitment site	0.03 (-0.11, 0.17)	0.67

Based on these results, the same variables used to predict sedentary time in the multivariate model were used to predict stepping time, with the addition of controlling waking time. The results, shown in Table 5.8, indicate that none of the variables were significantly associated with stepping time, although neighbourhood deprivation approached significance (p=0.05, Table 5.8).

Table 5.8. Multiple linear regression results of categorical variables predicting mean stepping time (log transformed). Significant values (p<0.05) are bolded (n=180).

Predictor variable	**β (95%CI)**	**p-value**
Age	0.01 (-0.17, 0.17)	0.99
BMI	0.02 (-0.14, 0.18)	0.81
Neighbourhood deprivation		
Most deprived (referent)		
Middle	0.03 (-0.13, 0.19)	0.72
Least deprived	-0.16 (-0.32, 0.01)	0.05
Income category		
<£20,000 (referent)		
£20-40,000	0.08 (-0.13, 0.29)	0.45
≥£40,000	0.04 (-0.18, 0.26)	0.74
Number of children at home		
None (referent)		
Any	-0.06 (-0.23, 0.11)	0.49
Marital status		
Married or cohabiting (referent)		
Single or living alone	0.14 (-0.03, 0.32)	0.11
Employment status		
Full time (referent)		
Part time	0.08 (-0.09, 0.26)	0.36
Not in paid work	-0.04 (-0.23, 0.15)	0.67
Smoking status during pregnancy		
Any smoking (referent)		
None	-0.08 (-0.23, 0.08)	0.33
Recruitment site	0.06 (-0.10, 0.23)	0.47
Waking time	-0.01 (-0.17, 0.15)	0.93

R^2=0.06, adjusted R^2=-0.01, p=0.62

5.3.3.3 Summary

In summary, results from multivariate models indicated that sedentary time among pregnant women in this sample had an inverse association with age (as age increased, sedentary time decreased), and was higher among those living in less-deprived neighbourhoods (although this was not a linear association) and among those with higher household incomes. Stepping time was not associated with any sociodemographic variables tested in the multivariate model.

5.3.4 Prevalence and predictors of television time and association with total sedentary time

5.3.4.1 Prevalence of prolonged (≥2 hours) television time

Among those who provided information about television watching in the second trimester (n=183), 68 (37.2%) reported watching television for ≥2 hours per day, while the remaining 115 (62.8%) reported watching less than 2 hours of television per day. The difference in prevalence of high television time between study site was near-significant (p=0.05); 43.3% of CHS participants and 29.1% of RVI participants reported watching ≥2 hours of television per day.

5.3.4.2 Predictors of prolonged (≥2 hours) television time

In unadjusted analyses (Table 5.9), none of the predictor variables were significantly associated with likelihood of watching ≥2 hours of television per day, although the highest income category approached significance (p=0.06; Table 5.9). In the multivariate model (Table 5.9), income category (those reporting ≥£40,000) emerged as a significant predictor of a lower likelihood of watching ≥2 hours of television per day; having any children at home approached significance (p=0.06).

The likelihood of watching ≥2 hours of television per day did not significantly differ by season (p=0.92), nor was day length associated with high television time (p=0.84).

Table 5.9. Univariate and multivariate predictors of prolonged (≥2 hours per day) television time

	Unadjusted		***Adjusted^***	
Predictor variable	***OR* (95%CI)**	***p-value***	***OR* (95%CI)**	***p-value***
BMI	0.99 (0.94, 1.05)	0.78	0.97 (0.91, 1.03)	0.37
Age	0.97 (0.92, 1.03)	0.40	0.99 (0.92, 1.06)	0.72
Neighbourhood deprivation				
Most deprived	1.00 (referent)		1.00 (referent)	
Middle	1.02 (0.46, 2.19)	0.96	1.77 (0.72, 4.42)	0.22
Least deprived	0.77 (0.33, 1.70)	0.52	1.09 (0.41, 2.79)	0.87
Income category				
<£20,0000	1.00 (referent)		1.00 (referent)	
£20-40,000	1.13 (0.55, 2.30)	0.74	0.94 (0.39, 2.24)	0.89
≥£40,000	0.46 (0.20, 1.01)	0.06	**0.33 (0.12, 0.91)**	**0.03**
Number of children at home				
None	1.00 (referent)		1.00 (referent)	
Any	0.58 (0.31, 1.09)	0.09	0.52 (0.26, 1.02)	0.06
Marital status				
Married or cohabiting	1.00 (referent)		1.00 (referent)	
Single or living alone	0.88 (0.34, 2.15)	0.78	0.62 (0.19, 1.93)	0.41

^Adjusted for all factors in the table plus recruitment site

Adjusted model AIC: 232.3

5.3.4.3 Associations between television time and objectively measured sedentary time

To test the associations between television time and objective measures of sedentary time, simple linear regression was run with category of television time (less than or ≥2 hours) predicting total sedentary time and prolonged sedentary time as measured by the activPAL; simple Poisson regression was run in the same way with breaks in sedentary time as the outcome variable. The results, shown in Table 5.10, indicate that total sedentary time and prolonged sedentary time are not significantly different between those who watch less than or at least 2 hours of television per day; however, those who watched fewer than 2 hours of television per day had more breaks in sedentary time per day, on average, than those who watched at least 2 hours. When considering activPAL-measured sedentary time that occurs from 6pm onwards, those who watch at least 2 hours of television per day had higher night-time sedentary time than those who watch less than 2 hours (Table 5.10). Night-time prolonged sedentary time and night-time breaks in sedentary time were not different between the two groups (Table 5.10).

Table 5.10. Association between television time (< or ≥2 hours) and activPAL-measured sedentary time (hours) using linear (total and prolonged sedentary time) and Poisson regression (breaks) with estimated marginal means (n=183).

	<2 hours (n=115)	≥2 hours (n=68)	p-value
All days			
Total sedentary time	9.43 (0.16, 9.73)	9.74 (9.35, 10.13)	0.22
Prolonged sedentary time	2.37 (2.22, 2.52)	2.42 (2.22, 2.62)	0.71
Breaks in sedentary time	53.5 (52.2, 54.9)	50.4 (48.7, 52.1)	**<0.01**
From 6pm to midnight			
Total sedentary time	3.73 (3.59, 3.87)	4.02 (3.84, 4.21)	**0.01**
Prolonged sedentary time	1.07 (0.99, 1.15)	1.15 (1.05, 1.26)	0.21
Breaks in sedentary time	18.4 (17.6, 19.3)	18.2 (17.3, 19.3)	0.83

5.3.4.4 Summary

In summary, income category was inversely associated with television time in the multivariate model, indicating that those in the highest income category were significantly less likely than those in the lowest income category to watch at least 2 hours of television per day. The association between television time and activPAL-measured sedentary time indicates that, in this sample, total sedentary time did not differ between those with high and low daily television time, although sedentary time at night (after 6pm) was significantly higher among those who watch ≥2 hours of television. Total breaks in sedentary time were significantly higher (by 3 per day) among those who watched fewer than 2 hours of television per day.

5.3.5 Prevalence and predictors of occupational sitting time and association with total sedentary time

5.3.5.1 Prevalence of occupational sitting time

Of those who provided valid accelerometry data, 154 were in paid work; just over half (n=78, 50.6%) reported sitting at work for at least 2 hours per day at work while the remainder (n=76, 49.4%) reported sitting for less than 2 hours per day. Thirty-six (18.8% of the total sample) were not in paid work; data were missing for 2 participants. Proportions of participants sitting less than 2 hours, at least 2 hours, and not in paid work did not significantly differ between study sites (p=0.15).

5.3.5.2 Predictors of occupational sitting time

Table 5.11 shows the number of employed participants (full-time and part-time) in each occupational class based on the SOC2010 classification and the proportion of those in each type of job who reported sitting at work for at least two hours per day. Because there were relatively few participants employed in managerial (n=7), skilled trades (n=1), and machine operatives (n=3), these occupational categories were merged with professional, caring/leisure, and elementary occupations, respectively. The right-hand column of Table 5.11 shows the distribution of sitting time among the merged categories.

Table 5.11. Sitting time at work during the second trimester (less than or ≥ 2 hours per day) by occupational classification (original and merged) among those still in paid work in the second trimester (n=153)

SOC 2010 job classification	n	Original SOC 2010distribution		Merged SOC 2010 distribution	
		<2 hours n(%)	≥2 hours n(%)	<2 hours n(%)	≥2 hours n(%)
Managers, directors, senior officials	7	2 (28.6%)	5 (71.4%)	13 (35.1%)	24 (64.9%)
Professional occupations	30	11 (36.7%)	19 (63.3%)		
Associate professional and technical occupations	15	4 (26.7%)	11 (73.3%)	4 (26.7%)	11 (73.3%)
Administrative and secretarial occupations	27	4 (14.8%)	23 (85.2%)	4 (14.8%)	23 (85.2%)
Skilled trades	1	1 (100%)	0 (0%)	30 (78.9%)	8 (21.1%)
Caring, leisure, and other service occupations	37	29 (78.4%)	8 (21.6%)		
Sales and customer service occupations	25	14 (56.0%)	11 (44.0%)	14 (56.0%)	11 (44.0%)
Machine operatives	3	2 (66.7%)	1 (33.3%)	10 (90.9%)	1 (9.1%)
Elementary occupations	8	8 (100%)	0 (0%)		

To examine whether the likelihood of sitting ≥2 hours at work per day significantly varied by job category, simple logistic regression was done in which job type predicted the likelihood of sitting for two hours per day. Compared to managers/professionals, those in skilled trades/caring occupations and those in machine operative/elementary occupations were significantly less likely to report sitting ≥2 hours per day at work (Table 5.12).

Table 5.12. Simple logistic regression predicting likelihood of sitting at work ≥2 hours per day in the second trimester by job type among those in paid work (n=154)

Job classification	OR (95%CI)	p-value
Managers, directors, senior officials, professional occupations	1.00 (referent)	
Associate professional and technical occupations	1.49 (0.41, 6.22)	0.56
Administrative and secretarial occupations	3.11 (0.94, 12.34)	0.08
Skilled trades, caring, leisure, and other service occupations	0.14 (0.05, 0.39)	**<0.001**
Sales and customer service occupations	0.43 (0.15, 1.19)	0.11
Machine operatives and elementary occupations	0.05 (0.01, 0.33)	**<0.01**

To examine the association between relevant sociodemographic characteristics and likelihood of sitting at work ≥2 hours per day, simple and multiple multinomial logistic regression models were run with age, BMI, neighbourhood deprivation, and income category included as predictor variables. In both unadjusted and adjusted models, income was significantly associated with occupational sitting time: those in the highest income category were significantly more likely to sit for ≥2 hours at work, while those in the middle income category were significantly less likely to not be in paid work (Table 5.13). Age, BMI, and neighbourhood deprivation were not associated with occupational sitting category.

Table 5.13. Univariate and multivariate predictors of occupational sitting using multinomial logistic regression (<2 hours per day is the referent category). Data are presented as OR (95%CI) and significant results (p<0.05) are bolded.

Predictor variable	Unadjusted models		Adjusted model^	
	Sit ≥ 2 hours	Not in paid work	Sit ≥ 2hours	Not in paid work
Age	**1.07 (1.01, 1.15)**	0.95 (0.87, 1.03)	1.04 (0.97, 1.12)	0.97 (0.88, 1.07)
BMI	0.99 (0.94, 1.05)	1.02 (0.95, 1.09)	0.98 (0.92, 1.05)	0.99 (0.91, 1.08)
Neighbourhood deprivation				
Most deprived	1.00 (referent)	1.00 (referent)	1.00 (referent)	1.00 (referent)
Middle	1.64 (0.71, 3.78)	0.92 (0.31, 2.75)	1.53 (0.58, 4.08)	1.17 (0.30, 4.61)
Least deprived	1.16 (0.52, 2.63)	0.49 (0.15, 1.64)	0.71 (0.27, 1.82)	1.11 (0.28, 4.43)
Income category				
Less than £20,000	1.00 (referent)	1.00 (referent)	1.00 (referent)	1.00 (referent)
£20-40,000	1.82 (0.77, 4.31)	**0.08 (0.02, 0.28)**	1.46 (0.59, 3.61)	**0.07 (0.02, 0.28)**
More than £40,000	**5.88 (2.26, 15.29)**	0.36 (0.11, 1.15)	**5.37 (1.89, 15.25)**	0.41 (0.11, 1.54)

^ Adjusted for all variables in the table plus recruitment site

5.3.5.3 Associations between occupational sitting time and objectively measured sedentary time

To test associations between occupational sitting time and indicators of total sedentary time, simple linear regression was run with occupational sitting category (</≥2 hours or not in paid work) predicting total sedentary time and prolonged sedentary time as measured by the activPAL; simple Poisson regression was run in the same way with breaks in sedentary time as the outcome variable. The results, shown in Table 5.14, indicate that those who sit for ≥2 hours per day at work have significantly higher total sedentary time than those who sit for less than 2 hours per day at work; the sedentary time of those not in paid work was not significantly different. There was no difference in prolonged sedentary time or number of breaks in sedentary time between the groups. When weekdays and weekend days were analysed separately, only total sedentary time on weekdays was significantly different between the groups (Table 5.14).

Table 5.14. Association between occupational sitting time (< or ≥2 hours or not in paid work) and activPAL-measured sedentary time using linear regression and estimated marginal means (n=184).

	<2 hours (n=56)	**≥2 hours (n=77)**	**Not in paid work (n=51)**
All days			
Total sedentary time	9.16 (8.81, 9.50)	9.93 (9.59, 10.27)*	9.66 (9.16, 10.17)
Prolonged sedentary time	2.32 (2.13, 2.50)	2.50 (2.32, 2.68)	2.25 (1.98, 2.52)
Breaks in sedentary time	51.9 (50.4, 53.5)	53.5 (51.9, 54.6)	51.9 (49.9, 54.6)
Weekdays			
Total sedentary time	8.87 (8.49, 9.25)	9.76 (9.39, 10.13)*	9.27 (8.72, 9.83)
Prolonged sedentary time	2.27 (2.06, 2.47)	2.46 (2.26, 2.66)	2.21 (1.90, 2.51)
Breaks in sedentary time	50.9 (49.4, 52.5)	52.5 (50.9, 54.1)	50.9 (48.4, 53.5)
Weekend days			
Total sedentary time	8.77 (8.39, 9.15)	9.21 (8.83, 9.58)	9.18 (8.63, 9.73)
Prolonged sedentary time	2.13 (1.89, 2.37)	2.33 (2.09, 2.57)	2.33 (1.98, 2.67)
Breaks in sedentary time	47.0 (45.6, 48.4)	48.9 (47.0, 50.4)	46.1 (43.8, 48.4)

* Indicates significantly different from < 2 hours (referent group)
Model adjusted for waking time

5.3.5.4 Summary

In summary, high occupational sitting time was less prevalent among pregnant women in caring and elementary occupations compared to those in managerial and professional occupations. In the adjusted model, high occupational sitting time was

higher amongst those in the highest income category. High occupational sitting time was associated with higher total sedentary time as measured by the activPAL for all days and on weekdays (but not weekend days), but there were no differences in prolonged sedentary time or breaks in sedentary time between those with high and low occupational sitting time and those not in paid work on all days.

5.4 Discussion

The results presented here for women with a risk factor for GDM are, to the best of my knowledge, the highest-quality data available to date that describe the sedentary time of pregnant women. Sedentary time was measured with an accelerometer especially designed for its measurement (activPAL) using a continuous wear protocol that ensures sedentary time across the entire day is captured. This study is also the first to provide an in-depth description of how sedentary time during pregnancy is patterned, in terms of both intra-individual variability (across days of the week and hours of the day) as well as inter-individual variability (sociodemographic correlates). Additionally, the results presented here are, to my knowledge, the first to describe the demographic patterning of television time and occupational sitting time during pregnancy and the association between these domains of self-reported sedentary time and total, objectively measured sedentary time. In the sections that follow, the findings concerning prevalence and patterns of objectively measured sedentary time are discussed first before discussing the findings related to subjectively measured television time and occupational sitting time.

5.4.1 Objectively measured sedentary time in the second trimester of pregnancy

Since it has been suggested that sedentary time may fluctuate across the trimesters of pregnancy (Nayak et al., 2016, Hawkins et al., 2017, McParlin et al., 2010), the sedentary time measured in the present study will be discussed alongside other studies that reported objective measures of sedentary time specifically during the second trimester of pregnancy to facilitate a more direct comparison.

Most studies that have reported objectively-measured sedentary time during the second trimester of pregnancy have reported lower sedentary time – both in absolute measurements (i.e., hours per day) and relative measurements (i.e., proportion of waking hours spent sedentary) – than the results reported in the present study

(mean 9.57 hours per day, 65.2% of waking hours). For example, two separate studies in the Netherlands reported that participants spent 7.5 hours per day sedentary which accounted for 59% of waking hours (Actigraph, obese population, n=46) (Nayak et al., 2016), and 8.8 hours of sedentary time per day which was 65% of waking hours (ActiTrainer, mostly normal weight, n=111) (Ruifrok et al., 2014). In the United States, an analysis of 2003-6 NHANES data reported a mean of 7.13 hours per day sedentary (56.5% of waking hours) in the second trimester (n=359; Actigraph) (Evenson and Wen, 2011), although another analysis using the same NHANES study cycle (with different data processing methods) reported 9.4 hours per day sedentary (63.8% of waking hours; n=294) (Hawkins et al., 2014). While the smaller amounts of sedentary time in these studies may be in part to do with different sample populations (e.g., no risk factors as in Evenson and Wen, 2011) in different countries, the difference in sedentary time is probably more likely to be attributable to differences in measurement protocols. The aforementioned studies each used waking wear protocols, which instruct the participants to remove the accelerometer for sleeping and for all water-based activities (showering, swimming, bathing). Such protocols are known to result in biased measurements in which the wearers may be more likely to remove the devices in the evening which, according to other data and the data shown here, may represent a portion of the day that has especially high sedentary time (Tudor-Locke et al., 2011a, McVeigh et al., 2016). Thus the higher absolute and relative measurements of sedentary time in this study probably reflect the measurement of end-of-day sedentary time that is more likely to not be accounted for in waking wear protocols (Tudor-Locke et al., 2011a).

Interestingly, the two studies with most similar values in terms of absolute sedentary time in the second trimester (9.6 and 9.8 hours per day, (Hayes et al., 2015, McParlin et al., 2010), respectively) took place in the UK among obese pregnant women, with one recruiting from one of the same antenatal clinics as in this study (RVI) (McParlin et al., 2010) and the other similarly having a predominantly deprived sample (Hayes et al., 2015). These similarities in sedentary time may reflect geographic or demographic similarities between our samples, although it is worth noting that the slightly shorter registered wear times (13.1 and 12.4 hours per day in Hayes et al., 2015 and McParlin et al., 2010, respectively) as a result of waking wear protocols limit direct comparisons between the measurements of these studies and the present study.

The only other study that has used a continuous wear protocol during pregnancy (using the activPAL and the SenseWear armband simultaneously) reported that participants spent 12.4 waking hours per day sedentary (n=40, mostly normal weight, United States) (DiFabio et al., 2015). This comparatively high amount of sedentary time may be somewhat explained by differences in sleep duration; DiFabio et al. (2015) reported that their sample slept for a mean of 7.0 hours per night in the second trimester (based on the SenseWear's measurement of sleep, which is subject to measurement error depending upon ambient conditions (Shin et al., 2015)). Thus, the differences in sedentary time between that sample and this study's sample may be attributable either to differences in number of waking hours available to spend sedentary, or differences in the measurement of sleep time.

5.4.2 Comparison of sedentary time during pregnancy with non-pregnant adults

In this sample, mean total sedentary time was 9.57 hours per day (65.2% of waking hours), with 2.4 of those hours coming from prolonged (≥30 minutes) sedentary bouts. On average, this sample had 52.8 sit-to-stand transitions ('breaks') per day.

As stated above, it is difficult to compare the sedentary time of this particular sample to the sedentary time reported in the literature among non-pregnant adults because of large variation in measurement protocols across studies (i.e., accelerometer type, wear protocol). Thus to simplify, the sedentary measures of this sample population are discussed in comparison to other studies that also used continuous-wear protocols with activPALs only among general adult populations not characterised by a particular pathology (i.e., studies using Actigraphs, waking wear protocols, or youth, older adults, or special populations are not addressed here).

In an Australian population-based study (n=678, mean age 58), mean sitting time was 8.8 hours per day, with 4.0 hours per day accumulated in prolonged bouts; the mean number of breaks in sedentary time was 54.1 (Bellettiere et al., 2017). A population-based study in the Netherlands (n=2449, aged 40-75) reported an average sedentary time of 9.44 hours per day which accounted for 60.1% of waking time (de Rooij et al., 2016). In a UK intervention study aiming to reduce sedentary time among adults at risk of type 2 diabetes (primarily due to obese BMI), baseline sedentary time was 8.9 and 9.0 hours per day for the intervention and control

groups, respectively (Biddle et al., 2015). A study of office-based workers in England (n=164) reported a mean sedentary time of 10.7 hours per day among the women in the sample, with an average of 52.2 sit-to-stand transitions per day (Smith et al., 2015); however, it should be noted that sedentary time was counted as any sitting between the hours of 7am and 11pm, which could mean that some night-time sleep was misclassified as sedentary time for any who went to bed before 11pm. Two small-scale studies (n=27 and 42) in Scotland among employed individuals reported mean sedentary times of 8.7 hours and 9.5 hours per day which accounted for 56% and 63.3% of waking time, respectively (Kirk et al., 2016, Gibson et al., 2017). Thus, the sedentary time among this study's sample does not seem obviously different than the sedentary time of other adult populations using similar measurement methods. However, the sample in this study had less waking time than what was reported in these studies due to the higher amount of night-time sleep, so although the mean sedentary time is not that different between this sample and other values among adult populations, its contribution to waking hours is relatively greater (by 1.9 to 9.2%).

Taken together, although no statistical comparisons can be made between the sedentary time of the present sample with that of non-pregnant adults, the sedentary time reported here seems generally similar to the sedentary time of other adult populations when the same type of accelerometry protocol was used.

5.4.3 Daily and diurnal patterns of sedentary time

When sedentary time was examined over the course of the week and the day, sedentary time was highest on Sundays. Most studies looking at the variability of sedentary time across days of the week have typically separated days as weekday versus weekend days, finding either that sedentary time on weekdays and weekend days was quite similar (Smith et al., 2015) or finding that sitting time was significantly higher on weekdays compared to weekend days (Gibson et al., 2017, Kirk et al., 2016). It may be that lumping Saturday and Sunday together as one weekend measure conceals the variation in sedentary time across the two days. McVeigh et al. (2016) examined daily variation in sedentary time and reported that Saturday had the lowest sedentary time (measured as sedentary to light ratio) of all of the days of the week; while sedentary time was not substantially higher on Sundays, MVPA was significantly lower. This is in agreement with the findings

presented here, that Saturday and Sunday are not similar and that Sunday may be a particularly 'restful' day, but this will depend on the population.

When sedentary time was examined over the course of the day, sedentary time was highest in the evenings after around 8pm with all days considered together. Data on hourly patterning of sedentary time across all waking hours are scarce given the relatively few studies that use continuous wear protocols, but McVeigh et al. (2016) and Bellettiere et al. (2015) similarly reported that sedentary time was highest in the evenings in their samples. Additionally, Smith et al. (2015) showed that weekday sitting peaked from 8-11pm and weekends after 6pm. This indicates that the hours with the highest proportion of sedentary time occur in what is likely to be discretionary leisure time at the end of the day.

5.4.4 Predictors of objectively measured sedentary time

In this sample, total sedentary time was negatively associated with age and positively associated with both individual-level and neighbourhood-level indicators of socioeconomic position. These are discussed in turn below.

5.4.4.1 Age

In this sample of pregnant women, age was negatively associated with total sitting time. Data on the association between age and objectively measured sedentary time in other samples are sparse (O'Donoghue et al., 2016). When adults of all ages are considered together, sedentary time has been shown to increase with age (Matthews et al., 2008). However, the opposite trend was seen in this sample, likely because the age range within the present sample was narrow as all participants were between the ages of 19 and 43. In a Belgian sample of adults, Van Dyck et al. (2010) reported that younger participants (ages 20-35) had higher sedentary time than those over the age of 35. This is consistent with findings by van Nassau et al. (2017) suggesting that those 35 years and older in a Belgian/Dutch sample were less likely to sit for 9 hours per day than those younger than 35. This may be reflective of the fact that the likelihood of having at least one child in the house was associated with age in this sample (data not shown), suggesting that the lower sedentary time of older participants may be due at least in part to looking after children.

5.4.4.2 Household income

In this sample, income was positively associated with total sedentary time, such that those who reported an annual household income of more than £40,000 had significantly higher sedentary time than those with an income of less than £20,000. The association between income and total sedentary time appeared to be primarily driven by occupational sitting time, which is discussed further below (section 5.4.6). The association between household income and objectively measured sedentary time has rarely been tested. In England, Stamatakis et al. (2014) reported that objectively measured sedentary time was higher among those with higher household income. During pregnancy, Evenson and Wen (2011) reported no association between household income and total sedentary time in the US.

5.4.4.3 Neighbourhood deprivation

Those who resided in the most deprived neighbourhoods had the lowest sedentary time in this sample. This association was significant despite income being included in the model, suggesting that area-level indicators of socioeconomic position may have separate effects on sedentary time.

The effect of neighbourhood deprivation in relation to sedentary time has not been extensively documented. In England, no association between area-level deprivation (as measured by quintiles based on the Index of Multiple Deprivation) and objectively measured sedentary time was reported (Stamatakis et al., 2014). Two studies have examined associations between sedentary time and neighbourhood income (although it should be noted that neighbourhood deprivation and neighbourhood income are not synonymous). In the United States, Kozo et al. (2012) reported that those who lived in higher-income neighbourhoods had higher objectively measured sedentary time. In Belgium, no association was reported between neighbourhood income and objectively measured sedentary time (Van Dyck et al., 2010).

The underlying explanation for the observed association between neighbourhood deprivation and sedentary time, independent of household income, is not immediately clear. It is possible that this pattern reflects the relative locations of these neighbourhoods. For example, areas with the lowest deprivation in England tend to be suburban or town-fringe, while more deprived areas tend to be among the

most urban and the most rural (ONS, 2009). Thus, it may be that those living in less-deprived areas might live further out from city centres, workplaces, or other frequented places and may thus more heavily rely on private transit to travel, thereby increasing sedentary time. In contrast, those living in urban areas, which tend to be among the most deprived, may rely more heavily on walking to get from place to place. Indeed, active travel data indicate that individuals living in more deprived areas rely more heavily on walking as a primary mode of transportation than those from less deprived areas (Rachele et al., 2015), because of higher walkability (i.e., street connectivity) in these areas as well as lower likelihood of having access to a car (Turrell et al., 2013).

5.4.5 Prevalence, predictors, and associations of television time with total sedentary time

5.4.5.1 Prevalence of television time

In this sample, just over one third (36.5%) reported watching two or more hours of television during the second trimester of pregnancy. Three other studies have reported prevalence of prolonged television time during pregnancy using the same cut-point of </≥2 hours (Oken et al., 2006, Gollenberg et al., 2010, Evenson and Wen, 2010b). The prevalence here is similar to that reported by Oken et al. (2006) (34%) who measured television time in the second trimester in the United States. Gollenberg et al. (2010) and Evenson and Wen (2010b) each reported higher prevalence in their samples (just over 60% in each). This may have to do sociodemographic differences between these samples and the sample in this study: half of Gollenberg's sample (Latina women in the US) were not in paid work, and Evenson and Wen's sample was representative of the US population (using NHANES data).

5.4.5.2 Predictors of television time

To date, no other studies have examined correlates of television time during pregnancy, making this the first study to report that those with higher income were less likely to watch more than two hours of television per day during pregnancy. The effect of children approached significance, suggesting that those with children may be less likely to watch ≥2 hours of television compared to those who do not have children.

The link between low socioeconomic position and high television time has been well documented, though never in pregnancy. Television time has been correlated with lower household income (Bowman, 2006, Shields and Tremblay, 2008, Burton et al., 2012b, Stamatakis et al., 2009), higher neighbourhood deprivation (Stamatakis et al., 2009), lower educational attainment (Teychenne et al., 2012, Van Dyck et al., 2011, Bowman, 2006, Shields and Tremblay, 2008, Clark et al., 2010, Stamatakis et al., 2009, Stamatakis et al., 2014, Huffman and Szafron, 2017), or not being in paid work (Burton et al., 2012b, Bowman, 2006, Shields and Tremblay, 2008, Clark et al., 2010, Huffman and Szafron, 2017). Clark et al. (2010) suggested that, among lower income groups, television time may be selected as an inexpensive leisure-time activity.

In a study of non-pregnant Australian adults, men and women with children watched significantly less television (treated as a continuous variable) than those without children (Burton et al., 2012a), consistent with the findings presented here. This may be indicative of differences in time allocation, as it has been suggested that women with children reallocate leisure time to childcare (Kimmel and Connelly, 2007).

5.4.5.3 Association with objectively measured sedentary time

In this sample, television time was not associated with total sedentary time. This is broadly consistent with other studies that have reported weak correlations between television time and objectively measured sedentary time (Clark et al., 2011a, Clark et al., 2015). This suggests that in this sample, as with others, television time is not a suitable proxy for total sedentary time.

However, this study is the first to my knowledge to test associations between television time and indicators of how sedentary time is accumulated (i.e., prolonged sedentary time and breaks), as well as the first to examine associations between television time and sedentary time specifically in the evening. In this sample, those who reported watching ≥2 hours of television in the second trimester had significantly higher sedentary time (by about 18 minutes) from 6pm onwards than those who watched fewer than 2 hours of television per day. Additionally, those who watched ≥2 hours of television had significantly fewer breaks in sedentary time across the entire day (roughly three fewer per day). It is unclear whether these

statistically significant differences have any clinically significant implications. However, these results contribute to the ongoing debate concerning whether the deleterious effects of television time on health outcomes are to do with how sitting time is patterned. Patterson et al. (2018) suggested that television time might be deleterious because it may affect postprandial glucose metabolism at the end of the day; in this sample, those who watched more television had higher sedentary time at night, which may be consistent with this suggestion. Furthermore, Patterson et al. (2018) and Saidj et al. (2013) have suggested that television time may be particularly prolonged in nature and might be detrimental for that reason. While television time was not associated with higher prolonged sedentary time, it was associated with fewer breaks in sedentary time across the entire day, lending some support to the possibility that high television time may be associated with fewer sit-to-stand transitions.

5.4.6 Occupational sitting time

5.4.6.1 Prevalence and predictors of occupational sitting time

In this sample, among those who were in paid work, just over 50% reported sitting for at least two hours per day at work, while the remainder reported sitting at work for fewer than 2 hours per day. Compared to those who worked in managerial and professional jobs, those who worked in skilled trades/caring/leisure/service occupations and machine operative/elementary occupations were significantly less likely to report sitting for at least 2 hours per day at work. This pattern is broadly consistent with broader associations in the general adult population in which white-collar and professional employees have higher sitting time at work than blue-collar employees (De Cocker et al., 2014, Duncan et al., 2010, Vandelanotte et al., 2013), and managers, professionals, and clerical workers having higher occupational sitting than trade workers and labourers (Chau et al., 2012b).

In this sample, those with the highest income (at least £40,000) were significantly more likely to sit for at least 2 hours at work compared to those with lower income. (less than £20,000). The association between high occupational sitting time and income has been demonstrated among adult populations in England (Stamatakis et al., 2014), Australia (Hadgraft et al., 2015, De Cocker et al., 2014) , and Germany (Wallmann-Sperlich et al., 2014).

5.4.6.2 Association with objectively measured sedentary time

In this sample, those who reported sitting at work for at least 2 hours per day had significantly higher total sedentary time than those who reported sitting for fewer than 2 hours per day, and higher sedentary time on weekdays but no difference on weekend days. This suggests that higher occupational sitting time is linked to higher total sedentary time overall. Few studies have examined the contribution of occupational sitting time to total objectively measured sedentary time in a sample that includes individuals with a variety of job types. Pulakka et al. (2018) reported that activPAL-measured sedentary time on weekdays was significantly higher among those in high- and intermediate-level occupations compared to those in low-level occupations among a sample of 2045 Dutch adults.

In this sample, prolonged sedentary time and breaks in sedentary time did not differ between the three occupational sitting groups. To my knowledge, the distribution of sedentary time has not been compared across individuals in different occupational sitting categories; rather, prolonged sitting has only been compared on working versus non-working days within the same individuals (e.g., (Parry and Starker, 2013, Thorp et al., 2012)). Although no information is available about when individuals were working to specifically measure prolonged sitting or breaks during working hours, the lack of overall difference in prolonged sitting time and breaks among occupational sitting groups may imply that occupational sitting is not necessarily linked to more broken up (total) sedentary time. Therefore, based on the data in this sample, the speculation that occupational sitting time may be less detrimental because it is frequently interrupted (Stamatakis et al., 2017, Saidj et al., 2013) is not supported.

5.5 Strengths and limitations

The results presented in this chapter should be interpreted with the following strengths and limitations in mind. The main strength of this chapter is the way in which total sedentary time was measured. The activPAL is the gold-standard device for measuring sedentary time in free-living studies because of its ability to distinguish postures and detect breaks in sedentary time. This measurement was further strengthened by the use of a continuous wear protocol, which avoids the bias of waking wear protocols and captures the sedentary time that takes place at the end of the day (where, in this sample, sedentary time was the highest). Furthermore, the

use of a validated, automated algorithm to detect night-time and non-wear time, cross-checked with visual heat maps and sleep diaries, increases the likelihood that sedentary time was correctly classified and not mistaken for sleep time. Another key strength of this study is the measurement of television time and occupational sitting time within the accelerometry sample which facilitates direct comparisons between the measures. Finally, the women in this sample represent a diverse range of sociodemographic backgrounds.

This chapter also has limitations that must be acknowledged. The measurements of television time and occupational sitting time were self-reported, which means they be subjected to reporting errors. Furthermore, the questionnaire through which these data were obtained had categorical time responses, which were then dichotomised as less than or at least 2 hours per day; continuous measures of each would have provided a better sense of the correlation between time spent in these domains of sedentary behaviour and objectively measured sedentary time. Additionally, working hours and days were not provided for each participant, which would have been useful to refine the measurement of occupational sitting time with objective measures. The other main limitation of this chapter is that these findings are specific to this group of women who have a risk factor for gestational diabetes. While the findings presented here are broadly consistent with other findings reported in the general population, it is unclear whether these findings can be generalised to the broader, low-risk pregnant population.

5.6 Conclusions

In this sample, different measures of sedentary time exhibited different sociodemographic patterning. Younger age, lower neighbourhood deprivation, and higher household income were associated with higher sedentary time. Higher household income was associated with higher occupational sitting time, while lower household income was associated with higher television time. The associations between total sedentary time and time spent in these sedentary behaviours suggested that occupational sitting time may substantially contribute to total sedentary time, and the differences in total sedentary time across income groups may be due to differences in occupational sitting time. Higher television time was not associated with higher total sedentary time overall, but was linked to higher sedentary time in the evening (after 6pm).

Chapter Six: Testing associations between sedentary time, sedentary behaviours, and pregnancy outcomes

6.1 Aims

Based on the literature reviewed in Chapter Two (section 2.7), this chapter aims to test the main hypotheses of this thesis, which are centred around testing the associations between total (activPAL-measured) sedentary time, time spent in two sedentary behaviours (television time and occupational sitting time), and pregnancy outcomes. The key outcome of interest in this study is GDM diagnosis and associated biomarkers (fasting and 2-hour plasma glucose levels). Other pregnancy outcomes of interest include systolic and diastolic blood pressure in the third trimester, gestational age at delivery, neonatal birthweight, and macrosomia. These outcome variables have been selected in order to provide higher-quality assessments of relationships previously tested with weaker methods in published literature (see sections 2.7.2 to 2.7.4 in Chapter Two).

The results are organised by measurement of sedentary time/behaviour. The results of 'traditional' tests are presented first, in which total sedentary time (minutes on valid/full days of measurement summed and divided by number of valid days) is the main predictor variable with stepping time and other relevant covariates controlled in the model. Second and third, predictor variables which indicate the distribution of sedentary time are tested: prolonged sedentary time (the sum of sedentary minutes accumulated in a bout lasting 30 minutes or more on valid days divided by the number of valid days) with stepping time controlled and breaks in sedentary time (number of sitting to standing transitions on valid days divided by number of valid days) with total sedentary time and stepping time controlled, along with appropriate covariates. Fourth, the results of compositional models are presented, which contain all four physical activity components (sedentary time, standing time, stepping time, and night-time sleep time on valid measurement days). These models describe the effect of time spent in each component with the outcome variable relative to time spent in the other three behaviours. Fifth, television time (less than or ≥ 2 hours per day) is used as a predictor variable for the same outcomes, with activPAL-measured stepping time controlled. Finally,

occupational sitting (less than or ≥2 hours per day, or not in paid work) is also used as a predictor variable, again with stepping time controlled.

6.2 Hypotheses

The following hypotheses are tested in this chapter:

1. Total sedentary time will be positively associated with gestational diabetes, fasting glucose, 2-hour glucose, systolic and diastolic blood pressure, gestational age at delivery, birthweight, and macrosomia
2. Prolonged sedentary time will be positively associated with gestational diabetes, fasting glucose, 2-hour glucose, systolic and diastolic blood pressure, gestational age at delivery, birthweight, and macrosomia
3. Breaks in sedentary time will be negatively associated with the same outcomes
4. In compositional models, sedentary time will have no association with any of these outcomes
5. Television time will be positively associated with these outcomes, and its effect will be larger than that of total sedentary time
6. Occupational sitting time will have no associations with these outcomes

6.3 Results

6.3.1 Descriptive statistics of outcome variables

The outcome variables presented in this chapter are summarised in Table 6.1, along with comparisons of means or frequencies by study site. The sample size for each outcome is provided in the table. Twelve participants with valid accelerometry data did not have GTT results. For these participants, it is known whether they developed GDM during the pregnancy (n=4 did) based on other measurements such as home glucose monitoring, but fasting and 2-hour glucose levels were not available for them (see section 4.5.4 for full explanation).

Fasting glucose was significantly higher at CHS compared to the RVI, while diastolic blood pressure was significantly higher at the RVI compared to CHS. Gestational diabetes incidence, 2-hour glucose levels, systolic blood pressure, gestational age at delivery, birthweight, and macrosomia did not differ between the two study sites (Table 6.1).

Table 6.1. Descriptive statistics of outcome variables among the sample of participants who had valid accelerometry data sets with comparison between study sites using chi-square analyses (categorical variables) and independent t-tests (continuous variables).

Outcome variable	**Total sample**	**CHS**	**RVI**	**p-value**
Gestational diabetes incidence				
	n=192	n=109	n=83	p-value
Diagnosed with gestational diabetes *n (%)*	31 (16.1%)	19 (17.4%)	12 (14.5%)	0.58
Plasma glucose levels				
	n=180	n=103	n=77	p-value
Fasting plasma glucose (mmol/litre) *Mean (SD)**	4.64 (0.51)	4.71 (0.54)	4.53 (0.46)	**0.02**
2-hour plasma glucose (mmol/litre) *Mean (SD)**	6.22 (1.47)	6.37 (1.50)	6.03 (1.41)	0.12
Mean blood pressure after 30 weeks' gestation				
	n=184	n=106	n=78	p-value
Systolic blood pressure *Mean (SD)*	118.45 (9.99)	117.92 (9.13)	119.17 (11.08)	0.42
Diastolic blood pressure *Mean (SD)*	71.85 (7.38)	70.31 (6.39)	73.95 (8.13)	**0.001**
Gestational age at delivery among those who delivery vaginally or via emergency caesarean				
	n=157	n=92	n=65	p-value
Mean (SD)	39.22 (2.14)	39.26 (2.05)	39.18 (2.28)	0.83
Birthweight (grams)				
	n=190	n=108	n=82	p-value
Mean (SD)	3464.3 (656.6)	3462.0 (647.0)	3467.4 (673.1)	0.96
Macrosomia				
	n=190	n=108	n=82	p-value
Macrosomia *n (%)*	28 (14.74%)	15 (13.89%)	13 (15.85%)	0.71
No macrosomia *n (%)*	162 (85.26%)	93 (86.11%)	69 (84.15%)	

* T-tests were done on log-transformed values; the back-transformed means are presented here

6.3.2 Identification of relevant covariates

Relevant covariates (beyond age, recruitment site, waking time, and stepping time) were identified based on significant associations in simple logistic or linear regression models for binary or continuous outcomes, respectively, for variables that were suspected to possibly have an association with the outcome based on other literature.

The full results from the univariate analyses are provided in Appendix 13. Potential covariates that had significant associations with the outcome variable ($p<0.05$), as shown in detail in Appendix 13 and summarised in Table 6.2, were included as covariates in the multiple regression models.

Table 6.2. Control variables included in all models for each outcome variable (see tables in Appendix 13 for full models)

Outcome	Included covariate(s)	Appendix table for reference
Gestational diabetes	BMI Previous GDM	A2
Fasting and 2-hour glucose levels	BMI	A3, A4
Blood pressure	BMI Parity Smoking during pregnancy	A5
Gestational age at delivery	N/A	A6
Birthweight	Parity Sex of the baby Gestational age at birth Smoking during pregnancy GDM diagnosis	A7
Macrosomia	Gestational age at delivery GDM diagnosis	A8

6.3.3 Total sedentary time

6.3.3.1 Gestational diabetes diagnosis

Total sedentary time did not significantly predict gestational diabetes diagnosis (Table 6.3).

Table 6.3. Multiple logistic regression results predicting GDM diagnosis with total sedentary time (n=186)

Predictor variable	OR (95% CI)	p-value
Sedentary time	1.003 (0.998, 1.008)	0.24
Stepping time	1.000 (0.987, 1.013)	0.90
Age	1.012 (0.928, 1.103)	0.78
BMI	1.032 (0.954, 1.113)	0.42
Previous GDM	20.67 (4.33, 126.04)	**<0.001**
Recruitment site	0.723 (0.274, 1.797)	0.49
Waking time	0.797 (0.490, 1.264)	0.34

Model fit= AIC 164.72

6.3.3.2 Fasting plasma glucose levels

Multiple linear regression was used to test the association between total sedentary time and fasting plasma glucose, with stepping time, age, BMI, waking time, and recruitment site controlled in the model. Given that GDM is a pathological condition and the glucose levels of those with GDM may be affected differently than those without GDM, interaction terms between the accelerometry variables (sedentary time and stepping time) and GDM diagnosis were included after centring the accelerometry variables. The interaction terms between sedentary time and GDM diagnosis and stepping time and GDM diagnosis were both significant (p=0.03 and p=0.004, respectively).

Estimated marginal means of linear trends[30] were applied to this regression model, which indicated that, for those without GDM, sedentary time had a positive, significant association with fasting glucose (β=0.16 (95%CI 0.01, 0.31)), while the association between sedentary time and fasting glucose among those with GDM was not significant (Table 6.4). The unadjusted relationships between sedentary time and fasting glucose for those and without GDM is shown in Figure 6.1.

[30] Estimated marginal means of linear trends are comparable to estimated marginal means, but provide the regression coefficient with confidence intervals between two continuous variables separately by a grouping factor (in this case, GDM diagnosis). This was done using the *emtrends* function within the R package *emmeans*. No p-values are presented for estimated marginal means for linear trends because significance tests are only used for pair-wise comparisons; thus, significance is determined by confidence intervals that do not cross zero.

Estimated marginal means of linear trends were also applied to the interaction between stepping time and GDM; for those without GDM, stepping had a non-significant association with fasting glucose, while for those with GDM, the association was positive and significant (Table 6.4).

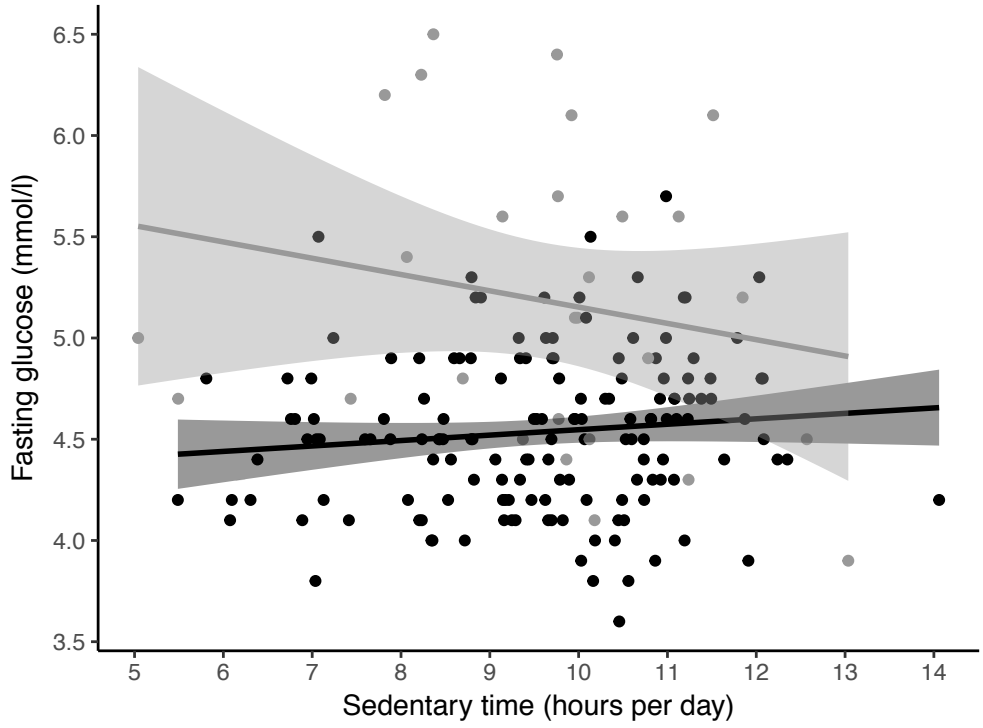
Table 6.4. Multiple linear regression results predicting fasting plasma glucose with total sedentary time (n=166)

Predictor variable	**β (95%CI)**	**p-value**
Sedentary time		
Without GDM	**0.16 (0.01, 0.31)**	
With GDM	-0.21 (-0.50, 0.09)	
Stepping time		
Without GDM	0.01 (-0.12, 0.15)	
With GDM	**0.58 (0.22, 0.94)**	
Age	0.04 (-0.10, 0.18)	0.57
BMI	**0.14 (0.01, 0.28)**	**0.04**
Recruitment site	-0.08 (-0.21, 0.06)	0.27
Waking time	**-0.15 (-0.29, -0.01)**	**0.04**

Fasting glucose was log-transformed due to positive skew

R^2=0.31, adjusted R^2=0.27, p<0.001

Figure 6.1. Scatterplot of the unadjusted association between total sedentary time and fasting plasma glucose, with separate fit lines for those without GDM (black) and those with GDM (grey). Bands indicate 95% confidence intervals.



6.3.3.3 2-hour plasma glucose levels

The interaction between total sedentary time and GDM status in relation to 2-hour glucose was near significant (p=0.06); the interaction with stepping time was not (p=0.91). Estimated marginal means for linear trends were applied, which indicated that, for those without GDM, sedentary time had a significant, positive relationship with 2-hour glucose, while the association was not significant for those with GDM (Table 6.5). These unadjusted associations are shown in Figure 6.2.

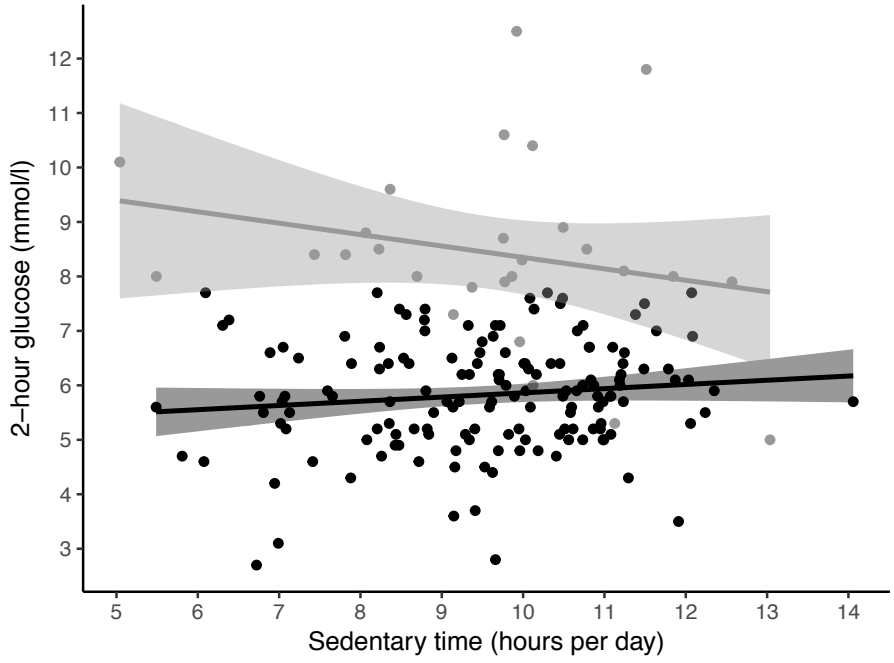
Table 6.5. Multiple linear regression results predicting 2-hour plasma glucose with total sedentary time (n=166)

Predictor variable	**β (95%CI)**	**p-value**
Sedentary time		
Without GDM	**0.15 (0.01, 0.30)**	
With GDM	-0.15 (-0.43, 0.14)	
Stepping time	-0.03 (-0.16, 0.09)	0.59
Age	0.11 (-0.02, 0.24)	0.10
BMI	0.01 (-0.13, 0.13)	0.99
Recruitment site	-0.10 (-0.23, 0.03)	0.12
Waking time	-0.12 (-0.12, 0.14)	0.08

2-hour glucose was log-transformed due to positive skew

R^2=0.37, adjusted R^2=0.34, p<0.001

Figure 6.2. Scatterplot of the unadjusted association between sedentary time and 2-hour plasma glucose, with separate fit lines for those without GDM (black) and those with GDM (grey). Bands indicate 95% confidence intervals.



6.3.3.4 Blood pressure

Total sedentary time did not significantly predict systolic (p=0.69) or diastolic (p=0.67) blood pressure; stepping time significantly, positively predicted systolic blood pressure (p=0.02), but this did not reach significance in relation to diastolic blood pressure (Table 6.6).

Table 6.6. Multiple linear regression predicting systolic blood pressure with total sedentary time (n=179)

	Systolic		**Diastolic**	
Predictor variable	**β (95%CI)**	**p-value**	**β (95%CI)**	**p-value**
Sedentary time	0.03 (-0.12, 0.18)	0.69	0.03 (-0.12, 0.19)	0.67
Stepping time	0.18 (0.03, 0.32)	**0.02**	0.13 (-0.02, 0.27)	0.08
Age	0.13 (-0.03, 0.29)	0.11	0.11 (-0.04, 0.27)	0.16
BMI	0.23 (0.07, 0.38)	**<0.01**	0.14 (-0.02, 0.29)	0.08
Parity				
None (referent)				
One	-0.15 (-0.31, 0.01)	0.08	-0.17 (-0.33, -0.01)	**0.04**
Two or more	-0.11 (-0.28, 0.05)	0.16	-0.11 (-0.27, 0.05)	0.18
Smoking status	0.08 (-0.07, 0.22)	0.30	-0.01 (-0.16, 0.13)	0.84
Recruitment site	0.13 (-0.02, 0.28)	0.09	0.28 (0.13, 0.43)	**<0.001**
Waking time	-0.04 (-0.20, 0.11)	0.58	-0.01 (-0.17, 0.15)	0.88

Systolic model R^2=0.12, adjusted R^2=0.07, p=0.009

Diastolic model R^2=0.12, adjusted R^2=0.08, p=0.006

6.3.3.5 Gestational age at delivery

Total sedentary time was not associated with gestational age, but stepping time was associated with decreased gestational age (Table 6.7).

Table 6.7. Multiple regression predicting gestational age with total sedentary time among those with vaginal or emergency caesarean deliveries (n=157)

Predictor variable	**β (95%CI)**	**p-value**
Sedentary time	0.01 (-0.16, 0.18)	0.89
Stepping time	-0.19 (-0.35, -0.03)	**0.02**
Age	-0.14 (-0.31, 0.03)	0.10
Recruitment site	0.01 (-0.15, 0.17)	0.90
Waking time	-0.06 (-0.23, 0.11)	0.49

R^2=0.07, adjusted R^2=0.04, p=0.06

6.3.3.6 Birthweight

Total sedentary time was not associated with birthweight (Table 6.8).

Table 6.8. Multiple linear regression results predicting birthweight with total sedentary time (n=175)

Predictor variable	**β (95%CI)**	**p-value**
Sedentary time	0.03 (-0.08, 0.14)	0.61
Stepping time	-0.01 (-0.11, 0.10)	0.89
Age	0.06 (-0.06, 0.17)	0.32
Parity		
None (referent)		
One	0.17 (0.05, 0.28)	**0.01**
Two or more	0.16 (0.04, 0.27)	**0.01**
Smoking status	-0.11 (-0.22, -0.01)	**0.03**
Sex of baby	-0.09 (-0.19, 0.01)	0.09
Gestational age at birth	0.70 (0.58, 0.81)	**<0.001**
GDM diagnosis	-0.02 (-0.13, 0.09)	0.67
Recruitment site	0.03 (-0.08, 0.14)	0.63
Waking time	-0.06 (-0.17, 0.05)	0.32

R^2=0.57, adjusted R^2=0.54, p<0.0001

6.3.3.7 Macrosomia

Total sedentary time was not associated with macrosomia (Table 6.9).

Table 6.9. Multiple logistic regression predicting macrosomia using total sedentary time (n=187)

Predictor variable	**OR (95% CI)**	**p-value**
Sedentary time	1.002 (0.997, 1.008)	0.36
Stepping time	1.008 (0.995, 1.021)	0.21
Age	1.04 (0.95, 1.14)	0.45
Gestational age at delivery	2.17 (1.48, 3.40)	**<0.001**
GDM status	0.66 (0.03, 4.36)	0.71
Recruitment site	1.16 (0.47, 2.85)	0.74
Waking time	0.73 (0.44, 1.19)	0.22

Model fit AIC 146.12

6.3.3.8 Summary

In summary, total sedentary time was positively associated with fasting and 2-hour glucose levels, among those who did not have GDM. Total sedentary time was not associated with incident GDM, systolic or diastolic blood pressure, gestational age at delivery, birthweight, or macrosomia.

6.3.4 Prolonged sedentary time

6.3.4.1 Gestational diabetes

Prolonged sedentary time was not associated with GDM diagnosis (Table 6.10).

Table 6.10. Multiple logistic regression results predicting gestational diabetes diagnosis with prolonged sedentary time (n=186)

Predictor variable	OR (95% CI)	p-value
Prolonged sedentary time	1.23 (0.74, 2.04)	0.43
Stepping time	1.000 (0.987, 1.011)	0.96
Age	1.004 (0.921, 1.095)	0.92
BMI	1.028 (0.950, 1.109)	0.48
Previous GDM	18.47 (3.96, 107.50)	**<0.001**
Recruitment site	0.735 (0.280, 1.823)	0.52
Waking time	0.866 (0.551, 1.340)	0.52

Prolonged sedentary time is sedentary time accumulated in bouts lasting ≥30 minutes
Model fit = AIC 165.54

6.3.4.2 Fasting glucose

The interaction between prolonged sedentary time and GDM status was not significant (p=0.10), so the results are presented for the sample as a whole. The results, shown in Table 6.11, indicate that prolonged sedentary time was associated with fasting glucose regardless of GDM status. This association is plotted in Figure 6.3.

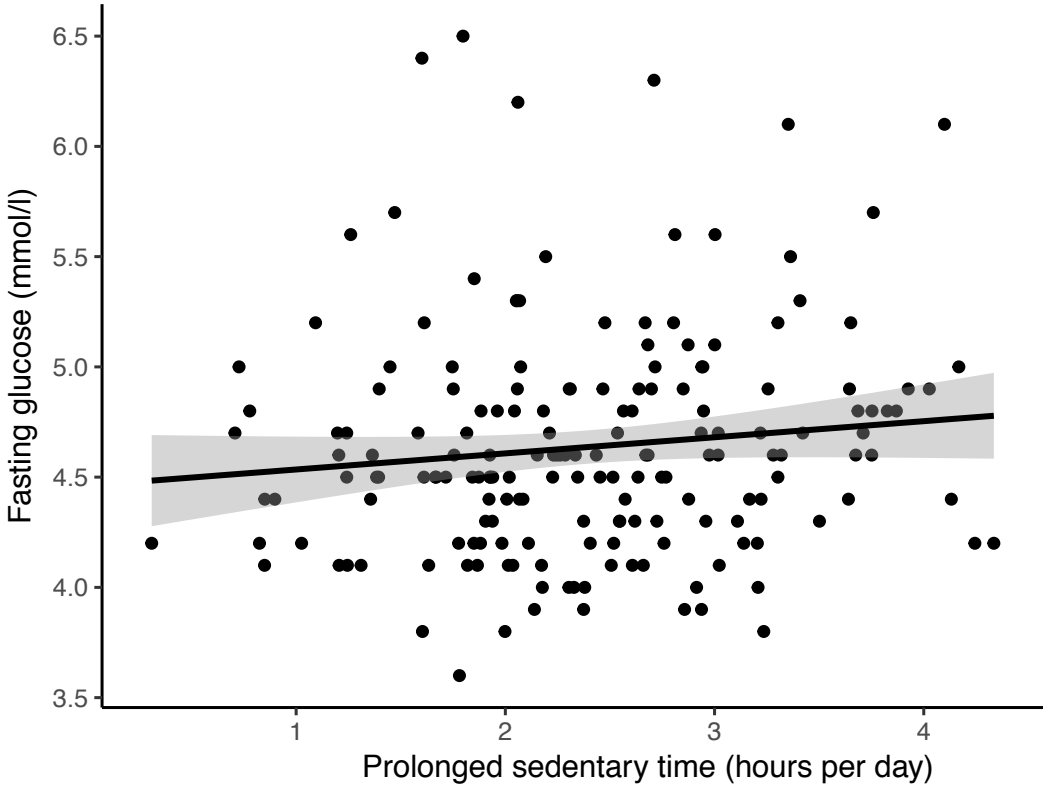
Table 6.11. Multiple linear regression results predicting fasting plasma glucose with prolonged sedentary time with (n=166)

Predictor variable	**β (95%CI)**	**p-value**
Prolonged sedentary time	0.15 (0.01, 0.30)	**0.04**
Stepping time	0.06 (-0.09, 0.20)	0.43
Age	0.05 (-0.10, 0.20)	0.51
BMI	0.17 (0.02, 0.33)	**0.03**
Recruitment site	-0.11 (-0.26, 0.05)	0.18
Waking time	-0.13 (-0.29, 0.03)	0.10

Fasting glucose was log-transformed due to positive skew

R^2=0.09, adjusted R^2=0.06, p<0.01

Figure 6.3. Scatterplot of the unadjusted association between prolonged sedentary time and fasting plasma glucose for the whole sample. Bands indicate 95% confidence intervals.



6.3.4.3 2-hour glucose

Interaction terms for the associations between prolonged sedentary time and GDM status in relation to 2-hour glucose were not significant (p=0.91), thus the results of the original model without interaction terms is shown in Table 6.12. No significant association between prolonged sedentary time and 2-hour glucose was found (Table 6.12).

Table 6.12. Multiple linear regression results predicting 2-hour plasma glucose with prolonged sedentary time (n=166)

Predictor variable	β (95%CI)	p-value
Prolonged sedentary time	0.07 (-0.08, 0.22)	0.39
Stepping time	-0.07 (-0.22, 0.08)	0.36
Age	0.10 (-0.06, 0.26)	0.21
BMI	0.05 (-0.11, 0.21)	0.54
Recruitment site	-0.10 (-0.26, 0.06)	0.20
Waking time	-0.11 (-0.27, 0.05)	0.19

2-hour glucose was log-transformed due to non-normality

R^2=0.04, adjusted R^2=0.01 p=0.32

6.3.4.4 Blood pressure

Prolonged sedentary time was not associated with systolic blood pressure (β=0.06 (95%CI -0.09, 0.20), p=0.44) or diastolic blood pressure (β=0.05 (95%CI -0.09, 0.19), p=0.49), after adjustment for stepping time, age, BMI, parity, smoking, waking time, and recruitment site. Stepping time was positively associated with systolic blood pressure (β=0.18 (95%CI 0.03, 0.32), p=0.02) in the same model.

6.3.4.5 Gestational age at delivery

Prolonged sedentary time was not significantly associated with gestational age (β=0.03 (95%CI -0.12, 0.19), p=0.69) after adjustment for stepping time, age, recruitment site, and waking time.

6.3.4.6 Birthweight

Prolonged sedentary time was not associated with birthweight (β=0.07 (95%CI -0.03, 0.17), p=0.18) after adjustment for age, parity, smoking status, sex of baby, gestational age at delivery, GDM status, stepping time, waking time, and recruitment site.

6.3.4.7 Macrosomia

Prolonged sedentary time was not associated with macrosomia (OR 1.48 (95%CI 0.87, 2.55), p=0.15) after adjustment for age, gestational age at delivery, GDM status, stepping time, waking time, and recruitment site.

6.3.4.8 Summary

In summary, prolonged sedentary time was associated with fasting glucose among the entire sample, regardless of GDM diagnosis. Prolonged sedentary time was not associated with incident GDM, 2-hour glucose, blood pressure, gestational age at delivery, birthweight, or macrosomia.

6.3.5 Breaks in sedentary time

6.3.5.1 Gestational diabetes

After controlling for total sedentary time, stepping time, age, BMI, previous GDM, recruitment site, and waking time, breaks in sedentary time did not significantly predict gestational diabetes diagnosis (OR 1.00 (95%CI 0.97, 1.03), p=0.98).

6.3.5.2 Fasting glucose

The interaction term for breaks and GDM status was significant (p=0.02). Estimated marginal means of linear trends indicated that breaks in sedentary time had a significant, negative association with fasting glucose among those with GDM but was not significantly associated with fasting glucose among those without GDM (Table 6.13). These unadjusted relationships are shown in Figure 6.4.

Table 6.13. Multiple linear regression results predicting fasting plasma glucose with breaks in sedentary time with interaction terms (n=166)

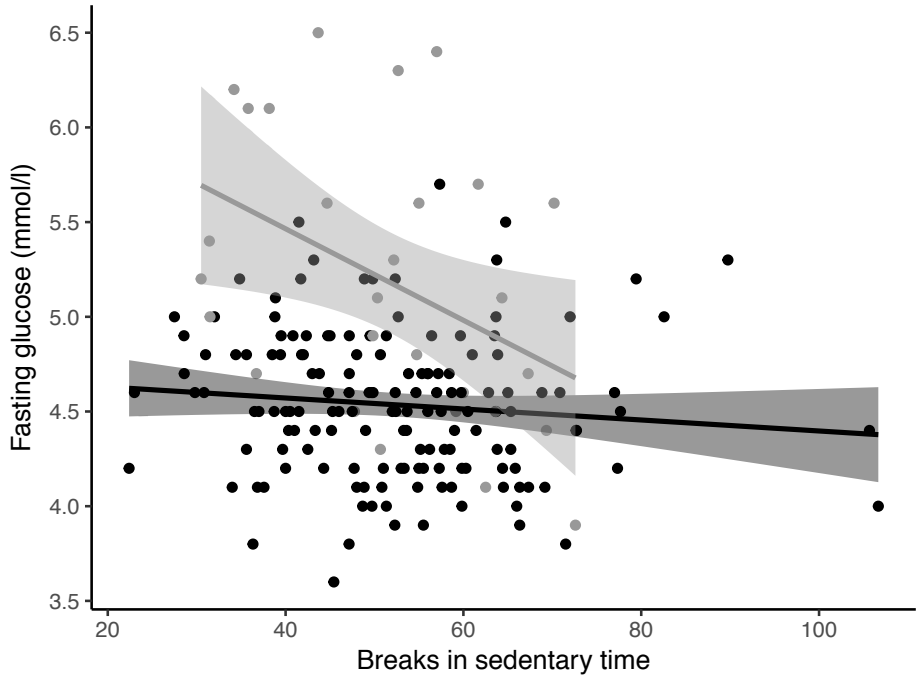
Predictor variable	**β (95%CI)**	**p-value**
Breaks		
Without GDM	-0.05 (-0.20, 0.09)	
With GDM	**-0.55 (-0.92, -0.17)**	
Age	0.02 (-0.12, 0.16)	0.76
Recruitment site	-0.06 (-0.20, 0.07)	0.37
Waking time	-0.14 (-0.28, 0.01)	0.07
BMI	0.10 (-0.04, 0.24)	0.17

Sedentary time and stepping time were also controlled in the model

Fasting glucose was log-transformed due to non-normality

R^2=0.34, adjusted R^2=0.30, p<0.001

Figure 6.4. Scatterplot of the unadjusted association between breaks in sedentary time and fasting plasma glucose, with separate fit lines for those without GDM (black) and those with GDM (grey). Bands indicate 95% confidence intervals.



6.3.5.3 2-hour glucose

The interaction for breaks in sedentary time and GDM status in relation to 2-hour glucose was significant (p<0.01). Estimated marginal means for linear trends indicated that, for those with GDM, breaks in sedentary time were significantly, negatively associated with 2-hour glucose, while this association was not significant for those without GDM (Table 6.14). This association is plotted in Figure 6.5.

Table 6.14. Multiple linear regression results predicting 2-hour plasma glucose with breaks in sedentary time including interaction terms (n=166)

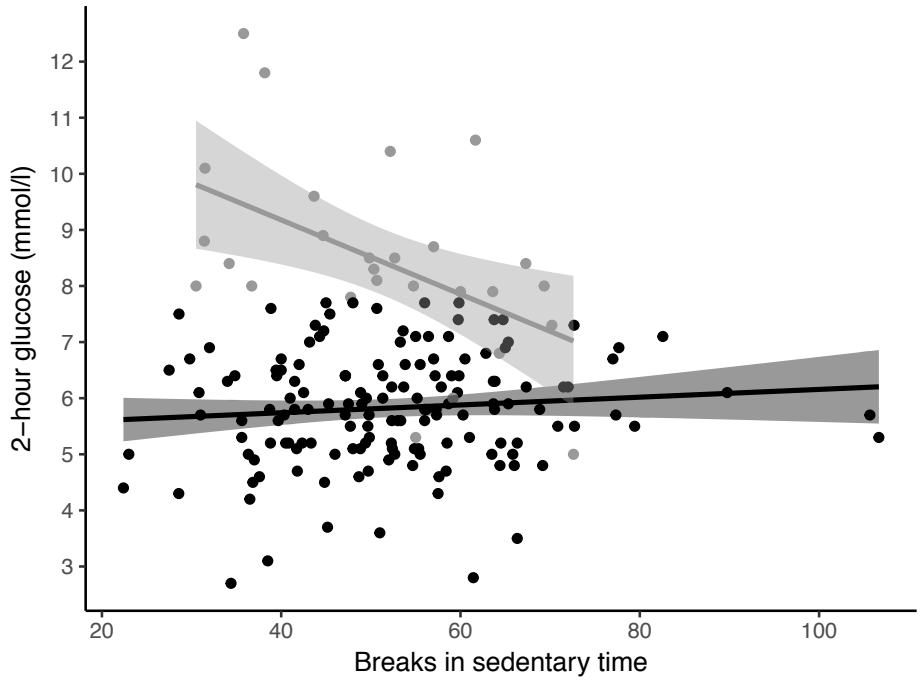
Predictor variable	**β (95%CI)**	**p-value**
Breaks		
Without GDM	0.13 (-0.01, 0.26)	
With GDM	**-0.40 (-0.77, -0.03)**	
Age	0.11 (-0.02, 0.25)	0.09
BMI	-0.02 (-0.16, 0.11)	0.72
Recruitment site	-0.10 (-0.23, 0.03)	0.12
Waking time	**-0.15 (-0.28, -0.01)**	**0.04**

Sedentary time and stepping time also controlled in the model

2-hour glucose was log-transformed due to positive skew

R^2=0.40, adjusted R^2=0.36, p<0.001

Figure 6.5. Scatterplot of the unadjusted association between breaks in sedentary time and 2-hour plasma glucose, with separate fit lines for those without GDM (black) and those with GDM (grey). Bands indicate 95% confidence intervals.



6.3.5.4 Blood pressure

Breaks in sedentary time were not associated with systolic blood pressure (β=0.10 (95%CI -0.08, 0.25), p=0.23) when total sedentary time and stepping time, along with the other covariates shown in Table 6.6, were controlled in the model. Similarly, breaks in sedentary time were not associated with diastolic blood pressure (β=0.09 (95%CI -0.06, 0.25), p=0.24).

6.3.5.5 Gestational age at delivery

Breaks in sedentary time were not associated with gestational age at delivery after controlling for total sedentary time, stepping time, age, recruitment site, and waking time (β=0.01 (95%CI -0.16, 0.18), p=0.96).

6.3.5.6 Birthweight

Breaks in sedentary time had no significant association with birthweight (β=-0.02 (95%CI -0.13, 0.09), p=0.74) after controlling for total sedentary and stepping time, age, parity, smoking status, sex of baby, gestational age at birth, GDM diagnosis, recruitment site, and waking time.

6.3.5.7 Macrosomia

Breaks in sedentary time were not associated with macrosomia after controlling for total sedentary time, stepping time, age, gestational age at delivery, GDM status, recruitment site, and waking time (OR 1.04 (95%CI 0.99, 1.08), p=0.07).

6.3.5.8 Summary

In summary, breaks in sedentary time were associated with lower fasting and 2-hour glucose levels among those who had GDM. Breaks in sedentary time were not associated with GDM, blood pressure, gestational age at delivery, birthweight, or macrosomia.

6.3.6 Compositional models

The outputs of compositional models can be interpreted as any other logistic or linear regression models, except that the odds ratios or effect sizes for the activity variables are to be interpreted as the *relative* effect of time spent in a given activity relative to time spent in the remaining activities (i.e., it is not the impact of a given activity 'independently' of the others).

6.3.6.1 Gestational diabetes

When considering the 24-hour composition, no physical activity components were significantly associated with GDM, although time spent standing approached significance (p=0.07; Table 6.15). When considering waking hours only (i.e., the composition of sedentary time + standing time + stepping time only), the results were not notably different (data not shown). The composition as a whole was also not associated with GDM (p=0.57).

Table 6.15. Multiple logistic regression results predicting gestational diabetes with 24-hour composition (n=186)

Predictor variable	**OR (95% CI)**	**p-value**
Sedentary time | others	0.64 (0.16, 2.35)	0.51
Stepping | others	0.46 (0.07, 2.62)	0.39
Standing | others	4.11 (0.99, 19.53)	0.07
Sleep | others	0.82 (0.06, 12.13)	0.89
Age	1.02 (0.93, 1.11)	0.68
BMI	1.03 (0.95, 1.12)	0.39
Previous GDM	21.45 (4.63, 125.47)	**<0.001**

Model fit AIC = 162.11

Recruitment site controlled in the model

6.3.6.2 Fasting glucose

No component of the compositional model was associated with fasting glucose (Table 6.16). The 24-hour composition as a whole was not associated with fasting glucose (p=0.74).

Table 6.16. Multiple linear regression model predicting fasting glucose with the 24-hour composition (n=169)

Predictor variable	γ	**p-value**
Sedentary time | others	-0.0001	0.99
Stepping time | others	0.03	0.29
Standing time | others	-0.02	0.51
Sleeping time | others	-0.01	0.85

Age, BMI, and recruitment site controlled in the model

Fasting glucose was log-transformed due to non-normality

R^2=0.06, adjusted R^2=0.03, p=0.09

6.3.6.3 2-hour glucose

No components of the composition had a significant association with 2-hour glucose (Table 6.17). The 24-hour composition was not significantly associated with 2-hour glucose (p=0.51).

Table 6.17. Multiple linear regression results predicting 2-hour glucose with the 24-hour composition.

Predictor variable	γ	**p-value**
Sedentary time | others	-0.03	0.64
Stepping | others	0.01	0.93
Standing | others	0.06	0.37
Sleep | others	-0.03	0.80

Age, BMI, and recruitment site controlled in the model
2-hour glucose was log-transformed due to non-normality
R^2=0.04, adjusted R^2=0.0.01, p=0.35

6.3.6.4 Blood pressure

In the compositional model, which controlled for age, BMI, parity, smoking status, and recruitment site, no accelerometry variable significantly predicted systolic (Table 6.18) or diastolic (Table 6.19) blood pressure. Furthermore, the composition as a whole was not associated with systolic (p=0.10) or diastolic (p=0.37) blood pressure.

Table 6.18. Multiple linear regression predicting mean systolic blood pressure using the 24-hour compositional model (n=171)

Predictor variable	γ	**p-value**
Sedentary time | others	0.51	0.82
Stepping time | others	-4.73	0.12
Standing time | others	4.29	0.11
Sleep time | others	-0.08	0.99

Age, BMI, parity, smoking status, and recruitment site controlled in the model
R^2=0.12, adjusted R^2=0.07, p=0.01

Table 6.19. Multiple linear regression predicting mean diastolic blood pressure using the 24-hour composition model (n=171)

Predictor variable	***b* (95%CI)**	**p-value**
Sedentary time | others	-0.25 (-3.59, 3.09)	0.88
Stepping time | others	-2.85 (-7.25, 1.54)	0.20
Standing time | others	2.51 (-1.39, 6.40)	0.21
Sleep time | others	0.60 (-6.16, 7.37)	0.86

Age, BMI, parity, smoking status, and recruitment site controlled in the model
R^2=0.12, adjusted R^2=0.08, p=0.007

6.3.6.5 Gestational age at delivery

No accelerometry variables in the compositional model were significantly associated with gestational age (Table 6.20). The composition as a whole was not associated with gestational age (p=0.08).

Table 6.20. Multiple regression predicting gestational age with 24-hour compositional data (n=157)

Predictor variable	γ	**p-value**
Sedentary time |others	-0.11 (-1.17, 0.95)	0.84
Stepping time | others	1.14 (-0.19, 2.46)	0.09
Standing time | others	-0.79 (-1.98, 0.40)	0.19
Sleep time | others	-0.23 (-2.39, 1.93)	0.83

Age and recruitment site controlled in the model

R^2=0.07, adjusted R^2=0.04, p=0.06

6.3.6.6 Birthweight

No component of the composition was associated with birthweight (Table 6.21). The composition as a whole also was not associated with birthweight (p=0.10).

Table 6.21. Multiple linear regression results predicting birthweight with 24-hour compositional data (n=175)

Predictor variable	γ	**p-value**
Sedentary time | others	23.7	0.83
Stepping time | others	-63.1	0.62
Standing time | others	55.7	0.70
Sleeping time | others	-16.34	0.94

Age, parity, smoking status, sex of baby, gestational age at delivery, GDM diagnosis, and recruitment site controlled in the model

R^2=0.57, adjusted R^2=0.54, p<0.001

6.3.6.7 Macrosomia

No physical activity variables in the compositional models were associated with macrosomia (Table 6.22). The composition as a whole was also not associated with macrosomia (p=0.96).

Table 6.22. Multiple logistic regression predicting macrosomia with 24-hour compositional data

Predictor variable	OR (95% CI)	p-value
Sedentary time | others	1.16 (0.33, 4.10)	0.82
Stepping time | others	0.65 (0.10, 4.03)	0.64
Standing time | others	1.36 (0.27, 6.71)	0.70
Sleeping time | others	0.98 (0.07, 1.39)	0.99

Age, gestational age at delivery, GDM status, and recruitment site were controlled in the model
Model fit AIC: 148.1

6.3.6.8 Summary

In summary, no components of the composition (sedentary time, stepping time, standing time, or sleeping time) were associated with any of the outcome variables tested. Furthermore, the compositions as a whole were not associated with any of the outcome variables.

6.3.7 Television time

6.3.7.1 Gestational diabetes

Television time (less than or at least 2 hours per day) in the second trimester was associated with GDM after controlling for activPAL-measured stepping time, age, BMI, previous GDM, and recruitment site (Table 6.23). The effect of television time was not attenuated when income category and neighbourhood deprivation were added to the model (OR 2.89 (95%CI 1.12, 7.85), p=0.03).

Table 6.23. Multiple logistic regression results predicting gestational diabetes with television time (≥ 2 hours per day versus <2 hours per day (referent), n=178)

Predictor variable	OR (95% CI)	p-value
Television time	3.03 (1.21, 7.96)	**0.02**
Stepping time	1.00 (0.98, 1.01)	0.70
Age	1.02 (0.94, 1.12)	0.60
BMI	1.03 (0.95, 1.12)	0.45
Previous GDM	21.54 (4.68, 122.62)	**<0.001**
Recruitment site	0.92 (0.34, 2.37)	0.86

Model fit AIC = 153.14

6.3.7.2 Fasting glucose

The interaction between television time and GDM was not significant (p=0.53), so the results are presented for the total sample. Television time was not associated with fasting glucose (Table 6.24).

Table 6.24. Multiple linear regression model predicting fasting glucose with television time (n=161)

Predictor variable	β (95%CI)	p-value
Television time	0.12 (-0.04, 0.27)	0.13
Stepping time	0.04 (-0.11, 0.19)	0.63
Age	0.05 (-0.10, 0.20)	0.52
BMI	0.19 (0.03, 0.35)	**0.02**
Recruitment site	-0.06 (-0.22, 0.10)	0.45

R^2=0.06, adjusted R^2=0.03, p=0.06

6.3.7.3 2-hour glucose

The interaction between television time and 2-hour glucose was not significant (p=0.08), so results are presented for the whole sample. Television time was not associated with 2-hour glucose (Table 6.25).

Table 6.25. Multiple linear regression results predicting 2-hour glucose with television time (<2 hours per day is the referent, n=160).

Predictor variable	β (95%CI)	p-value
Television time	0.05 (-0.11, 0.20)	0.57
Stepping time	-0.08 (-0.24, 0.07)	0.31
Age	0.12 (-0.04, 0.27)	0.14
BMI	0.06 (-0.11, 0.22)	0.49
Recruitment site	-0.09 (-0.25, 0.08)	0.31

R^2=0.03, adjusted R^2=0.01, p=0.39

2-hour glucose log-transformed

6.3.7.4 Blood pressure

Television time did not significantly predict systolic (β=0.02 (95%CI -0.14, 0.17), p=0.83) or diastolic blood pressure (β=-0.12 (95%CI -0.27, 0.03), p=0.12) after controlling for stepping time, age, BMI, parity, smoking status, and recruitment site.

6.3.7.5 Gestational age at delivery

Television time was not significantly associated with gestational age at delivery (β=-0.07 (95%CI -0.23, 0.09), p=0.37), after controlling for stepping time, age, and recruitment site.

6.3.7.6 Birthweight

Television time was not associated with birthweight (β=-0.02 (95%CI -0.13, 0.09), p=0.75) after controlling for stepping time, age, BMI, parity, sex of baby, smoking, gestational age at delivery, GDM diagnosis, and recruitment site.

6.3.7.7 Macrosomia

Television time did not predict macrosomia (OR 0.47 (95%CI 0.15, 1.25), p=0.15) after controlling for stepping time, age, gestational age at delivery, GDM status, and recruitment site.

6.3.7.8 Summary

In summary, television time was associated with GDM diagnosis in this sample, and this association remained significant after additionally controlling for income category and neighbourhood deprivation. Television time was not associated with glucose levels, blood pressure, gestational age at delivery, birthweight, or macrosomia.

6.3.8 Occupational sitting time

6.3.8.1 Gestational diabetes

Occupational sitting time (less than or at least 2 hours per day or not in paid work) in the second trimester was associated with GDM, such that those who sat at work for at least 2 hours per day at work had lower risk of GDM than those who sat for less than 2 hours per day; not being in paid work had no association (Table 6.26). When income category and neighbourhood deprivation were added to the same model, sitting for at least 2 hours per day at work was still associated with lower likelihood of GDM compared to sitting for less than 2 hours (OR 0.17 (95%CI 0.05, 0.53), p=0.004).

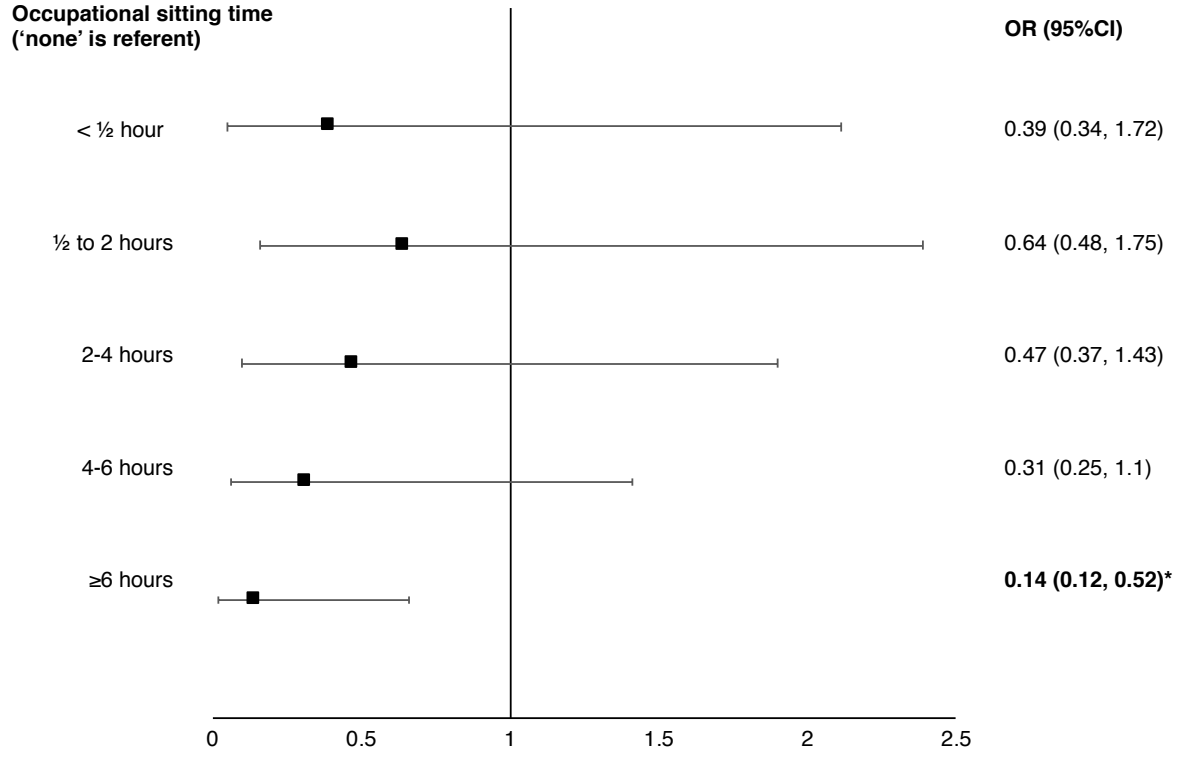
Table 6.26. Multiple logistic regression results predicting GDM with occupational sitting time (n=184)

Predictor variable	OR (95% CI)	p-value
Occupational sitting time		
Less than 2 hours	1.00 (referent)	
At least 2 hours	0.20 (0.06, 0.59)	**<0.01**
Not in paid work	0.67 (0.20, 1.94)	0.48
Stepping time	1.00 (0.99, 1.01)	0.72
Age	1.03 (0.94, 1.13)	0.52
BMI	1.03 (0.95, 1.11)	0.46
Previous GDM	17.60 (3.72, 108.71)	**<0.001**
Recruitment site	0.67 (0.25, 1.71)	0.42

Model fit AIC = 156.64

To examine whether this association was simply an artefact of dichotomising occupational sitting time, a forest plot was constructed using the original questionnaire responses in the multiple logistic regression model (Figure 6.6), with age, BMI, stepping time, recruitment site, and previous GDM controlled. Figure 6.6 indicates a generally linear trend toward lower GDM risk as occupational sitting time increases, with those who had the highest amount of occupational sitting time (≥6 hours per day) having significantly lower likelihood of GDM compared to those who reported no sitting at work. Odds ratios were not substantially changed when income category was added to the model (data not shown).

Figure 6.6. Forest plot of the associations between self-reported occupational sitting time in the second trimester and odds of GDM, adjusted for age, BMI, stepping time, recruitment site, and previous GDM.



6.3.8.2 Fasting glucose

Occupational sitting for the entire sample regardless of GDM status was significantly associated with fasting glucose (interaction terms were not applied because estimated marginal means of linear trends cannot be applied to factor interactions). Those who sat for at least two hours at work had significantly lower fasting glucose than those who sat for less than two hours at work; not being in paid work had no association (Table 6.27). Additionally adjusting for income and neighbourhood deprivation did not attenuate the association between high occupational sitting and lower fasting glucose (β=-0.37 (95%CI -0.54, -0.20), p<0.001).

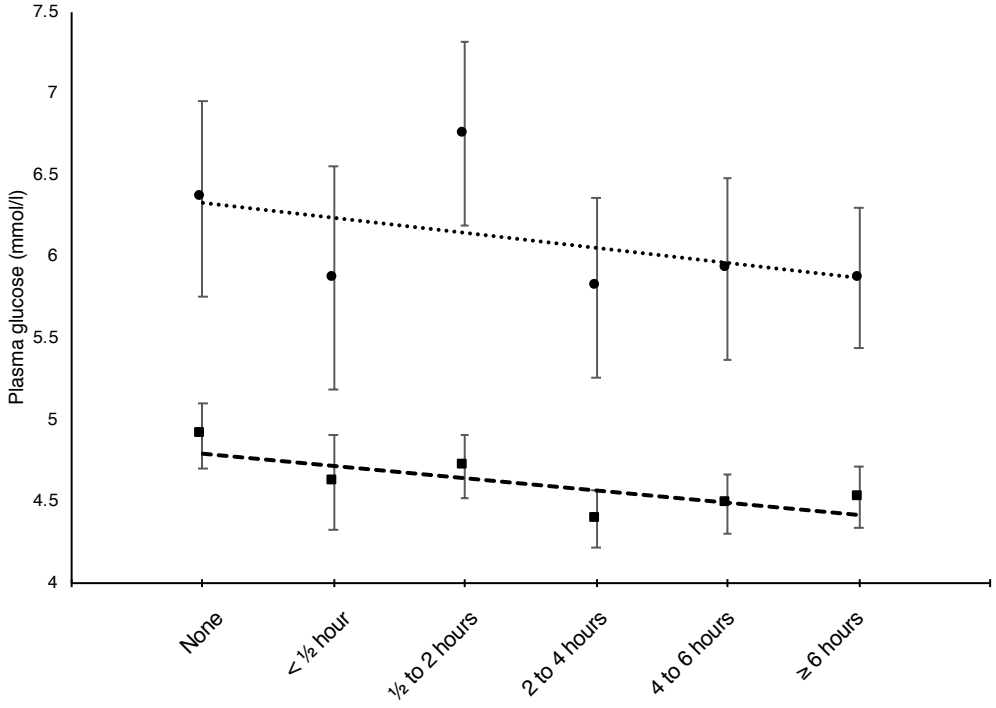
Table 6.27. Multiple linear regression model predicting fasting glucose with occupational sitting time (n=167)

Predictor variable	**β (95%CI)**	**p-value**
Occupational sitting time		
Less than 2 hours	Referent	
At least 2 hours	-0.37 (-0.52, -0.21)	**<0.001**
Not in paid work	-0.08 (-0.23, 0.08)	0.33
Stepping time	0.01 (-0.13, 0.15)	0.94
Age	0.12 (-0.03, 0.26)	0.11
BMI	0.20 (0.05, 0.24)	**<0.01**
Recruitment site	-0.12, (-0.27, 0.03)	0.11

R^2=0.18, adjusted R^2=0.15, p<0.001

As with the main GDM results, the unexpected negative association between occupational sitting time raised the concern that this was simply an artefact of the binary variable. The original questionnaire responses were entered into the same model. The results, shown in Figure 6.7, show a negative association between categories of self-reported sitting time and fasting glucose (squares with dashed line), confirming the unexpected direction of this association.

Figure 6.7. Estimated marginal means of fasting glucose (squares and dashed line) and 2-hour glucose (circles and dotted line) in relation to self-reported occupational sitting time in the second trimester, after adjustment for stepping, age, BMI, and recruitment site.



6.3.8.3 2-hour plasma glucose

Occupational sitting for the entire sample regardless of GDM status was significantly associated with 2-hour glucose (interaction terms were not applied because estimated marginal means of linear trends cannot be applied to factor interactions). Those who sat for at least 2 hours per day at work and those who were not in paid work had significantly lower 2-hour glucose than those who sat for less than 2 hours at work (Table 6.28). When income category and neighbourhood deprivation were added to the model, high occupational sitting remained significant (β=-0.24 (95%CI -0.42, -0.06), p=0.01), but the association with those not in paid work was attenuated (β=-0.13 (95%CI -0.31, 0.05), p=0.17). As with fasting glucose, the original responses to the occupational sitting question were plotted against 2-hour glucose levels with adjustment for the variables controlled here (Figure 6.7), indicating an inverse association between higher occupational sitting time and lower 2-hour glucose.

Table 6.28. Multiple linear regression results predicting 2-hour glucose with occupational sitting time (n=166).

Predictor variable	**β (95%CI)**	**p-value**
Occupational sitting time		
Less than 2 hours	Referent	
At least 2 hours	-0.21 (-0.38, -0.05)	**0.01**
Not in paid work	-0.17 (-0.34, -0.01)	**0.04**
Stepping time	-0.11 (-0.26, 0.04)	0.16
Age	0.09 (-0.06, 0.25)	
BMI	0.06 (-0.09, 0.22)	0.23
Recruitment site	-0.12 (-0.28, 0.04)	0.13

R^2=0.07, adjusted R^2=0.04, p=0.06

2-hour glucose log-transformed

6.3.8.4 Blood pressure

Occupational sitting time was not associated with systolic blood pressure. Compared to those who sat at work for less than 2 hours per day, the systolic blood pressure of those who sat for at least 2 hours per day (β=-0.05 (95%CI -0.20, 0.12), p=0.62) and those who were not in paid work (β=0.01 (-0.16, 0.18), p=0.89) was not significantly different after adjustment for age, BMI, stepping time, parity, smoking status, and recruitment site. Similarly, occupational sitting time was not associated with diastolic blood pressure (those who sat at least two hours per day, β=-0.06 (95%CI -

0.22, 0.11), p=0.49), those not in paid work, β=-0.06 (-0.23, 0.11), p=0.52, compared to those who sat for less than two hours per day).

6.3.8.5 Gestational age at delivery

Occupational sitting time was not associated with gestational age at delivery (≥2 hours (β=0.13 (95%CI -0.05, 0.30) p=0.16), not in paid work (β=0.05 (95%CI -0.13, 0.22), p=0.60) compared to those who sat <2 hours at work), after controlling for stepping time, age, and recruitment site.

6.3.8.6 Birthweight

Occupational sitting time was not associated with birthweight (≥2 hours per day β=0.01 (95%CI -0.11, 0.12, p=0.97), not in paid work β=0.07 (95%CI -0.05, 0.19, p=0.24) compared to those who sat <2 hours per day) after controlling for stepping time, age, parity, smoking, sex of the baby, gestational age at delivery, GDM status, and recruitment site.

6.3.8.7 Macrosomia

Occupational sitting time was not associated with macrosomia. The odds ratios for those sitting ≥2 hours per day and those not in paid work compared to those who sat less than 2 hours per day were OR 0.84 (95%CI 0.29, 2.47) p=0.75, and OR 2.16 (95%CI 0.64, 7.27) p=0.21, respectively, after adjustment for age, stepping time, gestational age at delivery, GDM status, and recruitment site.

6.3.8.8 Summary

High occupational sitting time (at least 2 hours per day) was associated with lower incidence of GDM, lower fasting glucose levels, and lower 2-hour glucose levels compared to those with low occupational sitting time (less than 2 hours per day); those not in paid work were not significantly different. Occupational sitting time had no association with blood pressure, gestational age at delivery, birthweight, or macrosomia.

6.4 Discussion

The data presented here represent, to the best of my knowledge, the first in-depth analysis of the associations between objectively-measured sedentary time during pregnancy using the activPAL and pregnancy outcomes and associated biomarkers among pregnant women with a risk factor for gestational diabetes. While this is not

the first study to test associations between television time during pregnancy and pregnancy outcomes, this is the first study to provide both objective measures of total sedentary time and self-reported television time and occupational sitting time within the same cohort during pregnancy, allowing direct comparisons between the effects associated with different measures of sitting time. As the main hypotheses of this chapter were in relation to gestational diabetes and glucose levels, the discussion that follows primarily focuses on these results, organised by measurement of sedentary time/behaviour, followed by brief comments on the remaining outcomes that were tested.

6.4.1 Total sedentary time

6.4.1.1 Gestational diabetes

This chapter tested the hypotheses that total sedentary time would be associated with increased risk of GDM. Contrary to expectation, total sedentary time was not associated with the development of GDM in this sample of high-risk pregnant women. To date, no other studies have tested an association between objectively measured sedentary time and GDM. One study examined an association between self-reported total sitting time (measured as tertiles of sedentary time in response to 'How much time do you spend sitting per day?') and GDM, reporting no association (Padmapriya et al., 2017). Given that self-reported measures of total sitting time have been shown to have poor validity when compared against the activPAL (Urda et al., 2017, Chastin et al., 2014, Chastin et al., 2018), the original impetus for this study was to use valid objective measures of sedentary time to clarify the hypothesised link between sedentary time and GDM; no association was found.

One possible explanation for the lack of association between sedentary time and GDM reported in this study is insufficient statistical power. The *a priori* power calculation for this study, based on the effect size of the association between sedentary time and the metabolic syndrome reported in a meta-analysis (1.73, (Edwardson et al., 2012)), indicated that a minimum sample size of 228 was required; the sample include in full analyses was only 184 (due to missing BMI cases). It should be noted, however, that the GDM incidence in this sample (16.1%) was higher than the expected incidence used in the power calculation (13.4%); using the actual GDM incidence and the effect size used in the *a priori* calculation (1.73), a

sample of 188 would be required, indicating that the final sample size was short by just four participants. It is possible that this slight shortage may result in an underpowered sample, although this seems unlikely. However, a meta-analysis published after this study was complete suggests that the effect size of total sitting time (mostly self-reported) in relation to type 2 diabetes may be much smaller (1.01) (Patterson et al., 2018), meaning that the effect size used in the power calculation may have been an overestimation. At the time that the calculation was done, two meta-analyses were available that synthesised data on sedentary time in relation to the metabolic syndrome (Edwardson et al., 2012) and television time in relation to type 2 diabetes (Wilmot et al., 2012), reporting effect sizes of 1.73 and 1.89, respectively. The former effect size (1.73) was used in the calculation because, although the outcome variable was not strictly diabetes, the methodologies of the studies that were included in that meta-analysis were slightly more variable than the other[31] and it was the more conservative estimated effect size of the two. The more recent meta-analysis (Patterson et al., 2018) pooled four studies that measured total sitting time (3 self-report, 1 accelerometry) in relation to type 2 diabetes and reported an effect size of 1.01 (95%CI 1.00, 1.01, $p<0.001$) after adjustment for physical activity, which is not only substantially smaller than the effect sizes reported by Edwardson et al. (2012) and Wilmot et al. (2012), but is also similar to the effect size reported in this chapter (1.00 (95%CI 0.998, 1.003)). The effect sizes reported by Edwardson et al. and Wilmot et al. may have been much larger because they relied heavily (Edwardson) or exclusively (Wilmot) on studies that used television-based measures, which have been suggested to have stronger associations with adverse cardio-metabolic outcomes than other measures of sedentary time (Whitaker et al., 2018, Patterson et al., 2018). This indicates that the effect size between total sedentary time and type 2 diabetes (Patterson et al., 2018) or GDM (as shown in this study) may be much smaller than previously suggested and would require a much larger sample size to detect an effect.[32]

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[31] The meta-analysis by Edwardson et al. (2012) contained 10 studies with the following measures of sedentary time: accelerometry (n=1), subjective total sitting (n=1), television (n=5), television + computer (n=2), television + computer + reading (n=1). The meta-analysis by Wilmot et al. (2012) contained 10 studies, all of which measured television time only.

[32] A power calculation using the effect size reported in Patterson et al. (2018) (1.01) and the GDM prevalence of the sample in this study (16.1%) indicates a minimum required sample size of 586,876 (power=0.80, two-tailed)

Gestational diabetes incidence was strongly predicted by previous diagnosis of GDM in this sample. Due to the small number of participants with previous GDM (n=9), it was not possible to stratify the models of sedentary time predicting GDM by previous GDM status in this study. Future studies may consider stratifying analyses if the sample size lends sufficient statistical power or recruiting nulliparous women only to the study to eliminate the effect of previous GDM on GDM incidence.

6.4.1.2 Glucose levels

This chapter also tested the hypotheses that total sedentary time would be associated with fasting and 2-hour glucose levels, and found that the effect of total sedentary time on glucose levels depended on GDM status. For those without GDM, total sedentary time positively predicted fasting and 2- hour glucose levels, while total sedentary time had no effect on glucose levels among those with GDM.

Three other studies have examined associations between objectively-measured total sedentary time during pregnancy and fasting glucose (Nayak et al., 2016, Hayes et al., 2014, Loprinzi et al., 2013) or 2-hour glucose (Hayes et al., 2014). Two of these studies (Nayak et al., 2016, Hayes et al., 2014) focused on women with a risk factor for gestational diabetes (high BMI), similar to the sample in this study. However, there were no reported associations between sedentary time and glucose levels in any of the three studies.

The discrepancies in results between these three studies and the present study may be due several key methodological limitations in the other studies that the present study sought to overcome. First, all three studies used waist-worn accelerometers which are subject to the limitations previously described. Second, two of these studies (Nayak et al., 2016, Hayes et al., 2014) had small sample sizes (n=46 and n=61, respectively) that may have been insufficient to detect associations. While Loprinzi et al. (2013) had a larger sample size (n=206), participants represented all three trimesters which may obscure possible associations because glucose regulation changes over the course of pregnancy (Nayak et al., 2016). Finally, as the findings of the present study indicated, the association between total sedentary time and glucose levels may depend on GDM status, and only by the application of the interaction term was this association made clear. This was not done in the other three studies: Nayak et al. (2016) and Hayes et al. (2014) included participants with

GDM in their analyses, while Loprinzi et al. (2013) presumably would have if any participants had or developed GDM (GDM diagnosis was not relevant to the study). Thus, it is possible that associations between total sedentary time and glucose levels require stratification by GDM status to be detected.

6.4.2 Prolonged sedentary time

This chapter tested the hypotheses that prolonged sedentary time would be associated with increased risk of GDM and higher glucose levels. Prolonged sedentary time was not associated with GDM or 2-hour glucose levels, but was associated with higher fasting glucose levels, regardless of GDM status. To date, no other studies have tested effects of prolonged sedentary time during pregnancy or in relation to incident type 2 diabetes among adult populations. Therefore, these findings are briefly related to literature on the associations between prolonged sedentary time and glucose levels among non-pregnant populations (including adults with type 2 diabetes) below.

Among the few free-living studies that have included prolonged sedentary time as a predictor variable, prolonged sedentary time (usually defined as sedentary time accumulated in bouts lasting ≥30 minutes but ≥20 minutes in one case) had no association with fasting glucose among individuals with type 2 diabetes (Healy et al., 2015, Falconer et al., 2015) or among population-based samples (Carson et al., 2014, Bellettiere et al., 2017); additionally, no association between prolonged sedentary time and 2-hour glucose in free-living settings has been reported (Bellettiere et al., 2017). To my knowledge, no laboratory-based studies have examined the association between prolonged sitting and fasting glucose; rather, postprandial glucose has classically been the focus with studies reporting links between prolonged sedentary time and increased postprandial glucose levels (e.g., Dunstan et al., 2012a, Henson et al., 2016). The association between prolonged sedentary time and fasting glucose in this study may be indicative of an effect of prolonged sedentary time on circulating glucose levels which could arise from the downregulation of GLUT4, a transport protein associated with glucose uptake, due to sustained muscular inactivity (Huang and Czech, 2007). However, this is speculative, and further research on the effects of prolonged sedentary time on glucose levels, especially in free-living contexts, is warranted.

6.4.3 Breaks in sedentary time

It was hypothesised that breaks in sedentary time would be associated with lower risk of GDM and lower fasting and 2-hour glucose levels. Breaks in sedentary time had no association with GDM. Breaks in sedentary time were associated with lower fasting and 2-hour glucose among those with GDM only. This result was unexpected as it was hypothesised that breaks in sedentary time would be beneficial for everyone regardless of GDM status.

Breaks in sedentary time have been associated with lower fasting glucose (but not 2-hour glucose) (Sardinha et al., 2017) and with time spent in euglycaemia (Paing et al., 2018) among individuals with type 2 diabetes in free-living studies, although this finding is not universal (Cooper et al., 2012). Among the general population, breaks in sedentary time have been associated with lower fasting glucose (Carson et al., 2014) and 2-hour glucose (Healy et al., 2008a) though null findings have also been reported (Henson et al., 2013a, Healy et al., 2011b, Bellettiere et al., 2017). One interpretation of the finding that breaks in sedentary time improve glucose among those with gestational diabetes is that breaks in sedentary time may have the most substantial benefits among those who have poorer glucose regulation. For example, experimental findings by Dempsey et al. (2018) indicated that postprandial glucose was adversely affected by a larger degree after prolonged sitting for those who had higher fasting glucose, suggesting that breaking up sedentary time may confer the greatest benefits to those with impaired glucose metabolism. Similarly, McCarthy et al. (2017) experimentally demonstrated the effects of breaks in sedentary time on postprandial glucose levels were the most dramatic among those with the lowest cardiorespiratory fitness. Therefore, it is possible that the findings of this study may be reflective of a broader trend in which breaks in sedentary time have the largest benefits for those with the poorest glucose regulation, although more research is needed to confirm this.

While the findings of the present study suggest that the distribution of sedentary time (prolonged sedentary time and breaks in sedentary time) may have an impact on glucose levels, it is important to note the limitations inherent in the reconstruction of sedentary patterns. More specifically, it should be noted that while laboratory-based studies consistently report that interruptions in sustained periods of sitting are associated with improved glucose metabolism compared to sustained sitting without

interruptions (Dunstan et al., 2012a, Chastin et al., 2015a, Henson et al., 2016), how this should be operationalised in the analysis of free-living accelerometry data is not as straightforward (Chastin et al., 2015a). The experimental findings in which interruptions in prolonged sitting improve glucose regulation has generally led to the assumption that breaks in sedentary time within free-living studies represent the same phenomenon (Chastin et al., 2015a). However, as has been pointed out by other researchers (Kim et al., 2015b), the physiological impact of breaks in sedentary time may require more contextual information about how and when these breaks are occurring (i.e., if breaks are truly interrupting prolonged sitting or if breaks are resulting from more frequent sit-to-stand transitions). For this reason, complex analytical strategies have been developed in order to gather more detailed insights into how sedentary time might be accumulated throughout a day in free-living contexts (Chastin and Granat, 2010). However, while some studies have applied these techniques (e.g., Bellettiere et al., 2017, van der Berg et al., 2016a), their use is not widespread and were thus not used in this study. Further development and uptake of similar approaches may be useful for deepening our understanding of the effects of the distribution of sedentary time on outcomes and biomarkers in future analyses.

6.4.4 Compositional models

This chapter tested the hypotheses that no components within the compositional model (sedentary time, stepping time, standing time, sleeping time) would be associated with GDM or glucose levels; indeed, the components of the compositional models had no associations with these outcomes. To date, very few studies have applied compositional data analysis techniques to accelerometry data, and no studies have used this approach on accelerometry data during pregnancy. Therefore, the compositional models presented in this chapter are discussed with reference to the scarce work that has been done in non-pregnant adult populations.

It was hypothesised that the compositional model would not significantly predict GDM risk or glucose levels. This hypothesis was informed by very limited evidence which has suggested that 24-hour time use may not predict glucose levels (Dumuid et al., 2018) but see (Chastin et al., 2015b). This may be due to the fact that the compositional models account for the opposing effects of the distributions of all

physical activity categories across the 24-hour day simultaneously. However, the most useful application of the compositional models is to predictively model the effects of substituting time spent in one 'activity' for another; it is from such models that compositional models have indicated that the effects of sedentary time are most pronounced when sitting time displaces time spent in MVPA (Chastin et al., 2015b, Dumuid et al., 2018). This substitution modelling requires that the composition as a whole are significantly associated with the outcome; however, this was not in the case for any outcomes in this study.

It should be noted that one key limitation of the compositional models is that they do not take the distribution of sedentary time into account. As was shown in this chapter, prolonged sedentary time and breaks in sedentary time may have unique effects on glucose levels, but there is presently no consensus on how these variables might best fit within a compositional model, although the importance of accounting for both the distribution of sedentary time and other factors such as sleep has been previously stated (Vincent et al., 2017). It may be that, when all 24 hours are taken into account, the effects of the distribution of sedentary time have very little impact, or the distribution could supersede the composition. Further developments in the applications of compositional models to physical activity data are needed to address this.

6.4.5 Television time

6.4.5.1 Gestational diabetes

It was hypothesised that television time would be associated with incident GDM, and that this association would be stronger than the association seen with total sedentary time. In this sample, television time (≥2 hours per day) was associated with GDM, even after controlling for stepping time and other covariates. Furthermore, the effect size of television time in relation to GDM (OR 3.03) was much larger than the effect size of total sedentary time (OR 1.003). This confirmed the hypothesis that the association between television time and GDM would be stronger than the association with total sedentary time, and is consistent with Patterson et al.'s (2018) finding that television time has a stronger association with type 2 diabetes.

Three other studies have tested associations between television time in mid-pregnancy and GDM or abnormal glucose tolerance[33] (Gollenberg et al., 2010, Oken et al., 2006, Padmapriya et al., 2017), and none of these studies reported associations. While it was expected that television time would be associated with GDM because of the consistent association between television time and type 2 diabetes (Wilmot et al., 2012, Biswas et al., 2015, Grontved and Hu, 2011), it is unclear why this association was found in this study but not in the other three. This discrepancy is not likely due to sample size, as the sample in this study (n=192) was much smaller than the samples of Oken (n=1805), Gollenberg (n=1006), and Padmapriya (n=1083). A more likely explanation may be that this sample included only women with a risk factor for GDM unlike the other studies, and as a result, the incidence of GDM was higher in this sample (16.1%) than in Oken's (5%) and Gollenberg's (3.3% GDM, 12% AGT), although the incidence in Padmaprya's sample (18.6%) was similar to this sample.

It is not clear why television time appears to have a stronger association with incident diabetes than total sitting time. Possible underlying reasons for this difference are currently being discussed in the literature and were reviewed in sections 2.4.1 and 2.4.2 and are discussed in turn here. The most popular speculation has been that television time may be associated with snacking and consumption of energy-dense foods (Patterson et al., 2018, Whitaker et al., 2018, Stamatakis et al., 2012a, Stamatakis et al., 2012b, Dunstan et al., 2010, Hu et al., 2003, Saidj et al., 2013, van der Ploeg and Hillsdon, 2017, Ekelund et al., 2016). There is evidence from a population-based sample in the US (n=9157, collected in 1994-6) suggesting that those who watched ≥2 hours of television per day consumed more energy from snacks than those who watched less than 2 hours of television per day (Bowman, 2006), but no information was available to indicate whether snacking and television time were concurrent. Data concerning dietary patterns were not collected in this study, primarily due to the substantial participant burden that this would add to the protocol. Thus, it was not possible to control for dietary factors in this study.

It has also been suggested that television time takes may interfere with postprandial glucose metabolism because it takes place at the end of the day (Patterson et al.,

[33] Defined in their study as a glucose reading of >135mg/dL following a non-fasting 1-hour 50g OGTT

2018, Ekelund et al., 2016). Data presented in Chapter 5 (Table 5.10, page 130) lend some support to this theory as those who watched television for ≥2 hours per day had higher sedentary time at night than those who watched less than 2 hours per day. However, it is unclear whether sedentary time at different times of day impacts glucose metabolism differently.

It has also been suggested that television time is deleterious because it may be more prolonged in nature, which may further impact glucose metabolism (Patterson et al., 2018, Saidj et al., 2013, van der Ploeg and Hillsdon, 2017, Ekelund et al., 2016). Findings in Chapter 5 (Table 5.10, page 130) indicate that prolonged sedentary time did not differ between those who watched less than or ≥ 2 hours of television per day, either across all waking hours or just in the evening hours. However, those who watched ≥2 hours of television per day had significantly fewer breaks in sedentary time throughout the day than those who watched <2 hours. This may lend some support to the suggestion that high television time is associated with fewer breaks in sedentary time, although it should be noted that the difference in number of sit-to-stand transitions between the two groups was only 3 per day; while this was *statistically* significant, it is not clear whether this is a *clinically* significant difference.

It has been suggested that television time is associated with particularly low levels of energy expenditure and muscular activation compared to other sedentary behaviours such as working at the computer or driving a car (Whitaker et al., 2018, Saidj et al., 2013, Pinto Pereira et al., 2012), and it is this lack of muscular activity that makes it so detrimental. While this may apply when television watching is occurring on its own (i.e., when one is completely immobile), there is evidence to suggest that television time is often accompanied by the concurrent use of computers, tablets, and phones (Segijn et al., 2017), indicating that it may be unrealistic to assume that people are completely immobile while watching television.

Finally, a suggested reason for the larger effect of television time is that it may be a marker of low socioeconomic status (Stamatakis et al., 2018) based on evidence that those who watch more television tend to be of lower income (Stamatakis et al., 2009), lower education (Shields and Tremblay, 2008), and higher neighbourhood deprivation (Stamatakis et al., 2009). In this sample, the association between television time and GDM was only slightly attenuated when household income and

neighbourhood deprivation were controlled in the model. This may indicate that the effect of television time is independent of these indicators of socioeconomic position, but that does not necessarily mean that the effect of television time has nothing to do with socioeconomic inequalities. At the very least, income category and relative neighbourhood deprivation do not fully capture socioeconomic position, nor do they account for other factors that contribute to socioeconomic gradients in health outcomes, such as job security and control, psychosocial stress, and housing conditions (Marmot et al., 2008, Marmot et al., 2012).

6.4.5.2 Glucose levels

In this sample, television time was not associated with glucose levels. To my knowledge, only two studies have tested self-reported time spent in sedentary behaviours in relation to glucose levels during pregnancy. Padmapriya et al. (2017) tested associations between television time (</≥3 hours per day) during pregnancy and fasting and 2-hour glucose levels with adjustment for BMI, previous GDM, and other covariates (not including physical activity), reporting no associations. Gollenberg et al. (2010) reported that their composite measure of sedentary time (tertiles of television time plus sitting at work, plus exercise reverse scored) was associated with 1-hour post-load glucose levels; however, as was pointed out earlier in this discussion, this measurement is difficult to interpret, partly because over half of the sample was not in paid work.

In non-pregnant adult populations, the association between television time and continuous measures of glucose has rarely been examined. In cross-sectional studies, television time has been linked to higher fasting (Healy et al., 2008b) and 2-hour glucose levels (Healy et al., 2008b, Dunstan et al., 2007) in adults without diagnosed type 2 diabetes, although this has been shown to be attenuated by waist circumference, at least among women (Thorp et al., 2010).

6.4.6 Occupational sitting time

In this sample, high occupational sitting time (≥2 hours per day) was associated with *lower* incidence of GDM and *lower* fasting and 2-hour glucose levels compared to those who sat at work for less than 2 hours per day; not being in paid work had no effect. Given the inconsistent associations between high occupational sitting and poor health outcomes including type 2 diabetes (van Uffelen et al., 2010), it was

hypothesised that high occupational sitting would have no association with GDM; thus, the *negative* association with GDM was unexpected.

The negative association between occupational sitting time and glucose levels has been previously shown. A study by Saidj et al. (2013) compared the effects of leisure-time sitting (including television time) and occupational sitting (both continuous measures) in relation to fasting glucose levels. In their graphs (shown previously in Figure 2.1), occupational sitting time similarly showed a *negative* association with fasting glucose from 0 to 4 hours of occupational sitting time, after which glucose levels increased before decreasing again. Thus, this finding is consistent with the finding in this chapter, suggesting that occupational sitting time may be inversely associated with fasting glucose levels.

To my knowledge, no studies to date have examined associations between time spent sitting at work and incidence of GDM. Gollenberg et al. (2010) used a composite measure of television time plus time spent sitting at work (plus low physical activity) and found a positive association with abnormal glucose tolerance; however, the relative contributions of television time and occupational sitting time are unclear, especially given that the majority of their sample was not in paid work.

In general, suggestions to explain the inconsistent association between occupational sitting time and type 2 diabetes (as well as other health outcomes) have mirrored the suggestions for associations with television time. For example, some have speculated that occupational sitting time may be more frequently interrupted (and thus less prolonged) than other types/domains of sitting (primarily television time) (Saidj et al., 2013). The results presented in Chapter 5 (Table 5.14, page 134), however, do not support this, as they suggested that prolonged sedentary time and breaks in sedentary time across all waking hours did not significantly differ between those with high and low occupational sitting time. While these differences are not specific to how sitting time was accumulated specifically during working hours in this sample, they suggest that the overall distribution of sedentary time is not significantly different between occupational sitting groups.

The other suggested reason for the weak and inconsistent associations between occupational sitting time and poor health outcomes is the correlation between high

occupational sitting and high socioeconomic position (Stamatakis et al., 2013, van der Ploeg et al., 2015, Pinto Pereira et al., 2012). Indeed, the findings within Chapter 5 (Table 5.13, page 133) indicate that those in the highest income category were significantly more likely to sit for at least 2 hours per day at work than those in the lowest income category, supporting this suggestion. However, controlling for household income and neighbourhood deprivation did not attenuate the association between occupational sitting time and incident GDM. This may indicate that there are other confounding factors associated with higher-level occupations at play. For example, analyses of the Scottish Health Survey and associated occupational surveys (2008-2011), which used the same occupational classification as was used in this study (see Table 4.4), indicated that the proportion of men and women who self-rated their health as 'good' was highest among those in higher-level occupations and lowest among those in lower-level occupations, with a clear gradient in between (Taulbut and McCartney, 2017); this gradient persisted after controlling for qualifications, household income, and health-related 'behavioural' factors such as smoking, alcohol consumption, obesity, and physical activity. Importantly, indicators of employment *quality* also followed this gradient, such that inadequate working hours, job precariousness, and lack of control at work were much more highly concentrated among lower-level occupations compared to higher-level occupations (Taulbut and McCartney, 2017). Given the evidence to suggest that employment conditions are linked to health inequalities for factors that extend beyond income (Benach et al., 2014), the unexpected association between higher sitting time and lower likelihood of GDM may be a reflection of this.

6.4.7 Sedentary time/behaviour and other pregnancy biomarkers and outcomes

No measures of sedentary time (total, prolonged, breaks, compositional, television time, or occupational sitting time) were associated with any of the remaining pregnancy outcomes and biomarkers tested in this chapter (systolic and diastolic blood pressure, preterm delivery, gestational age, birthweight, or macrosomia).

To date, objectively measured sedentary time during pregnancy has been tested in association with systolic and diastolic blood pressure (Loprinzi et al., 2013), gestational age at birth (Ruifrok et al., 2014), birthweight (Ruifrok et al., 2014), and macrosomia (Reid et al., 2014, Hayes et al., 2014). All but one (Reid et al., 2014) of these studies reported null associations between sedentary time and the outcomes of

interest. It should be noted that, similarly to the studies described above in relation to glucose levels, these studies have methodological limitations in the measurement of sedentary time. Loprinzi et al. (2013), Hayes et al. (2014), and Ruifrok et al. (2014) used waist-worn accelerometers with waking wear protocols, which are subject to the limitations discussed in the previous section. Reid et al. (2014) used a case-control study design in which the sedentary time of women who were predicted to deliver macrosomic infants based on ultrasound measurement or previous incidence of macrosomic birth (study group) was compared to the sedentary time of women who were not predicted to have macrosomic babies (control group); thus, sedentary time was not used to predict the likelihood of macrosomia. Although the impetus for test these associations was to improve upon these methodological limitations by using higher-quality measures of sedentary time and more robust statistical methods, the null findings were replicated. This may be due to an insufficient sample size; since the power calculation was conducted using GDM as the key outcome variable, it is unknown whether the sample size would be large enough to detect an effect if there is one, and the dearth of literature on these associations makes estimations of the expected effect sizes difficult. The lack of associations found here may alternatively suggest that sedentary time during pregnancy may have no association with these pregnancy outcomes, but more research is needed to confirm this.

A more consistent predictor of the pregnancy outcomes and biomarkers tested in this study was parity, which was negatively associated with systolic and diastolic blood pressure and positively associated with birthweight. Pregnancy remodels the body, especially cardiovascular system, and these effects have been shown to persist well beyond the gestational period (Clapp and Capeless, 1997) and are suggested to result in lower blood pressure in subsequent pregnancies (Strevens et al., 2001). This change in cardiovascular structure may also underlie the increase in birthweight in subsequent pregnancies due to increased nutrient availability to the foetus (Khong et al., 2003). It is possible that factors such as parity may have more pronounced effects on pregnancy outcomes and associated biomarkers than factors such as sedentary time, especially in relation to outcomes related to cardiovascular physiology, but more research is needed to untangle these relationships.

6.5 Strengths and limitations

A key strength of this chapter's findings is the validity of the measurement of sedentary time, using a 'gold standard' methodology (Kim et al., 2015a, Kozey-Keadle et al., 2011).

However, this study is not without limitations. Most notably, because the main inclusion criterion for participants in this study was a risk factor for gestational diabetes to ensure all participants had the glucose tolerance test, the findings of this study are restricted to this 'high-risk' group. It is uncertain whether the associations between sedentary time and pregnancy outcomes, including but not limited to GDM and glucose levels, may be different among the general pregnant population that is not characterised by risk status. Additionally, no data were available on dietary factors for this sample. Given the possible confounding effect that snacking and poor dietary habits may have on the effects of television time (Bowman, 2006), controlling for this information would have been helpful.

6.6 Conclusions

The findings of this chapter suggest that, while sedentary time (total, prolonged, breaks, or compositional) was not associated with risk of incident GDM, total sedentary time was associated with higher glucose levels among those who do not have GDM, while breaks in sedentary time were associated with lower glucose levels among those with GDM. This study has been the first to date to report associations between activPAL-measured sedentary time and glucose levels during pregnancy, and these findings may have implications for the management of glucose levels during pregnancy.

The findings of this chapter also indicate that high television time was associated with increased likelihood of GDM (but was not associated with glucose levels), while high occupational sitting time was associated with decreased likelihood of GDM and decreased glucose levels. These patterns, particularly in comparison to the patterns seen with objectively measured sedentary time, are in broad agreement with the literature that suggests that the effects of television time are particularly detrimental, and occupational sitting is not (van Uffelen et al., 2010, Stamatakis et al., 2013, Stamatakis et al., 2018). Further research is needed to understand whether these differences in effects are due to differences in measurement limitations, the

patterning, timing, or type of sedentary time, dietary or socioeconomic confounding, or combinations of all of these factors.

No aspects of sedentary time (total, prolonged, breaks, or compositional) were associated with any pregnancy outcomes or associated biomarkers tested in this study (systolic and diastolic blood pressure, gestational age at birth, birthweight, or macrosomia). There are no high-quality studies with which to compare the findings of this study, but it is possible that the null findings by this and previous studies may indicate that pregnancy outcomes may be particularly resilient to the effects of sedentary time and may be more powerfully affected by other factors. Further research that uses high-quality measurements of sedentary time is needed to build upon these findings.

Chapter Seven: The influences of social context and being 'at risk' on sedentary time and physical activity during pregnancy

7.1 Aims

Based on the literature reviewed in Chapter Two (section 2.9), the primary aim of this chapter is to highlight the social contexts of sedentary time and physical activity during pregnancy using data from semi-structured interviews. This chapter and its analysis is not intended to anthropologically theorise sedentary time and physical activity during pregnancy, but aims to bring the social context of pregnancy to the forefront, in contrast to the marginal regard for interpersonal factors within the physical activity literature. The secondary aim is of this chapter is to examine how women interpret what it means to be 'at risk' for gestational diabetes (GDM) and what effect, if any, being 'at risk' for GDM has on physical activity during pregnancy.

7.2 Research questions

1. What is the influence of social context in relation to sedentary time and physical activity during pregnancy?
2. Does being 'at risk' for gestational diabetes have any impact on physical activity during pregnancy?

7.3 Results

7.3.1 Interview participant sample description

A minority of study participants (n=96, 29.4%) expressed interest in being interviewed on the enrolment form. In total, 26 women were contacted (based on convenience of location and timing of their 30 weeks' gestation), and 18 consented to be interviewed (69.2% response rate). All interview participants had taken part in the accelerometry portion of the study. All women were at least 30 weeks' gestation at the time of the interview (mean=31.8 weeks, range 30.3-34.1), marking the early portion of the third trimester. One participant agreed to the interview but went into premature labour at 30 weeks before the interview took place; she still wished to take part, so she was interviewed on the postnatal ward one week after giving birth.

A summary of the characteristics of the interview participants is provided in Table 7.4.1. The mean age of participants was 34 (range 26-40). Most (n=8; 44%) lived in neighbourhoods associated with the most deprived neighbourhood tertile, four (22%) lived in the middle tertile, and six lived (33%) in the least deprived tertile. Half were in the middle income group; only one belonged to the low-income group. All interview participants were born in the UK; one identified as South Asian (94% White British). All participants were employed at least part-time, although five participants had already begun maternity leave at the time of the interview. The majority (n=11, 61%) had previously given birth; the remaining seven were nulliparous. All interview participants were married or cohabiting. These characteristics generally resemble the accelerometry sample (refer to Table 5.2), with the exception that all interview participants were employed and married/cohabiting, while most (but not all) of the accelerometry sample was employed (81%) or married/cohabiting (87%). Four of the participants interviewed (22%) were diagnosed with GDM, and they knew of their diagnosis prior to the interview.

Fourteen (78%) interview participants provided valid accelerometer data sets[34]. When the sedentary and stepping time (total time on valid days divided by number of valid days) of the interview participants was compared to median values for the entire accelerometry sample (n=192), half of the interview participants' sedentary time was above the median (n=7) and half was below (Table 7.1). Only four interview participants' stepping time was greater than or equal to the median stepping time of the entire accelerometry sample. This suggests that those who elected to take part in the interview had comparable sedentary time and, in general, lower stepping time compared to the rest of the study sample and were thus not necessarily 'especially' active.

[34] Of the four that did not provide valid data sets, three data sets were invalid when battery problems were being experienced with the activPALs. The fourth had an allergic reaction to the adhesive so did not wear the device for four full days.

Table 7.1 Interview participant characteristics

Pseudonym	Age	Neighbourhood deprivation tertile	Household income category	Parity*	BMI category**	Above/below median sedentary time***	Above/below median stepping time***
Louise	38	Middle	Between £20-40,000	1	Obese	N/A	N/A
Jessica	34	Most deprived	Less than £20,000	0	Obese	Below	Below
Sarah	34	Middle	Above £40,000	0	Obese	N/A	N/A
Leah	32	Most deprived	Between £20-40,000	1	Normal weight	Above	Above
Kathryn	34	Least deprived	Above £40,000	0	Overweight	Belowz	Below
Natalie	39	Most deprived	Between £20-40,000	0	Normal weight	Above	Above
Paige	33	Most deprived	Between £20-40,000	0	Obese	Below	Above
Sally	34	Most deprived	Between £20-40,000	1	Overweight	Above	Below
Bethany	27	Most deprived	Between £20-40,000	0	Obese	Above	Below
Julie	40	Least deprived	Above £40,000	3	Obese	Below	Below
Shannon	37	Most deprived	Above £40,000	1	Obese	Above	Below
Michelle	35	Middle	Above £40,000	1	Obese	Above	Above
Molly	28	Least deprived	Above £40,000	1	Obese	Below	Below
Nicola	32	Least deprived	Above £40,000	1	Obese	N/A	N/A
Kelly	33	Middle	Above £40,000	0	Normal weight	Below	Below
Rachel	26	Most deprived	Between £20-40,000	1	Obese	N/A	N/A
Samantha	37	Least deprived	Between £20-40,000	1	Obese	Above	Below
Leanne	35	Least deprived	Between £20-40,000	1	Normal weight	Below	Below

* Parity defined here as number of previous full-term pregnancies

** BMI categories defined as normal weight (18.5-24.9kgm^{-2}), overweight (25.0-29.9kgm^{-2}), and obese ≥30kgm^{-2}) based on the booking BMI recorded in their medical notes. While it is acknowledged that such weight categories are social constructions (Lupton et al., 2013), they are reported here because of the way in which weight category determines the pathway of care (particularly for obesity).

*** Median sedentary time (582.8 minutes per day) and stepping time (44.8 minutes per day) based on total accelerometry sample; 'N/A' denotes those who did not provide valid accelerometry data sets

The key themes that emerged from analyses of the interviews are presented below, and the findings are supported by quotations from participants. Pseudonyms have been used in place of participants' names, and personally identifiable details (e.g., names of partners) within quotations have been redacted. All dialect and grammatical errors are preserved within the quotations. All direct quotations are italicised; these are put in quotation marks and included in line with the text if they are short phrases (e.g., *'quotation'*), or are isolated as blocks of text if they are longer. Where the quotation does not provide sufficient context, clarifications have been added in brackets (e.g., *he [partner] says*). In instances where participants deviated from the topic of interest, omitted words are denoted by an ellipsis (…). To add context, participants' ages and parity (number of previous full-term pregnancies) are included at the end of quotations.

7.3.2 Social expectation for pregnant women to slow down and/or do nothing

The most predominant theme that emerged from the data was women's perceptions that others in their everyday lives expected them to slow down, which manifested as a simultaneous encouragement to sit and do nothing and discouragement from engaging in physical activity. These are described separately in more detail below.

7.3.2.1 Social encouragement of sitting and resting (sedentary time)

Women in this sample were commonly encouraged to just *'sit down'*, *'sit still'*, *'take it easy'*, *'put your feet up'*, and *'rest.'* Partners/husbands were particularly insistent that their pregnant partners sit down, although they were not the only ones making such comments:

> *He [partner] always used to, 'Just go and sit down. Get a cuppa and just sit down, will ya?' I can't sit down…I've gotta be doing something…[so] he started coming—'cause I was living at me mam's house, so he would come-- instead of going straight to our house to keep doing the work on the house, after work he would come to me mam's to make sure I got a cuppa and sat down for at least five minutes 'cause he knew as soon as he left, I was back up doing stuff.* Kelly, 33, first pregnancy

> *[Talking to husband about plans for a day at home]: I said, 'Oh great, I can get this done and this done and this done...' 'No, no, you can't do that, you*

need to rest. No, no, you can't do any of that.' I said to him, 'I don't have to sit all the time, I can do some things.' 'No, no, no, no, no, have to rest, have to rest. Get the rest while you can.' [Laughs] Sarah, 34, first pregnancy

At work, a lot of the younger girls are just like, 'Sit down, just sit down. I can do this, I can do this.' Jessica, 34, first pregnancy

When asked why they thought people encouraged them to sit so much, a number of respondents referred to and described the '*stereotypical pregnant woman*' as the key origin and perpetuator of this expectation, described in several different ways:

You're pregnant and you're meant to sit there, aren't you, and be fat and that's the stereotype, isn't it? You're meant to sit there and not do anything. Kathryn, 34, first pregnancy

I think it's just ingrained in society—it's this image that has kind of come out that women should sit at home and drink tea and eat cake [laughs] and be on a sofa with their feet up forever. Michelle, 35, second pregnancy

A lot of people just don't think it's okay to work or do anything and it's [pregnancy is] pretty much just laying on a couch, you know? Paige, 33, first pregnancy

While many felt that they were expected to conform to this expectation to sit down during their pregnancies, a number of women vocalised their resistance to conforming to it:

I didn't wanna be one of these people, 'Ohh I'm pregnant, I can't be doing anything'… I know people who just take it [pregnancy] as a god-given right not to do anything and wonder why they don't enjoy it. Kelly, 33, first pregnancy

To me, it's [pregnancy is] no reason just to sit and have everyone wait on you hand and foot, as nice as that would be. Jessica, 34, first pregnancy

Additionally, most women identified the expectation to *'sit around'* during their pregnancies as a remnant from the past that is now outdated:

They're worried because I'm pregnant, you know, like especially the older generation. It's like you shouldn't be doing anything when you're

pregnant. I think they'd prefer if I was like, had confinement like they used to have in the Tudor times or something, I don't know. Nicola, 32, second pregnancy

…or ,you know, like the old wives' tales, you know, like when you think back, people used to go into confinement. Leanne, 35, second pregnancy

I think it's just like a traditional sort of thing that people think… I think it's probably just from the past, really. Shannon, 37, second pregnancy

People would have been on bed rest 50 years ago, wouldn't they. They wouldn't have done anything. Julie, 40, fourth pregnancy

Several women also highlighted that they felt they were being regarded as sick patients who were weak, which generally reflects the social construction of pregnancy as a fragile, medical condition. Women referred to others' attitudes that *'pregnant women have to be wrapped in cotton wool,' 'just the usual thing of people trying to wrap you up in cotton wool or bubble wrap and it can get quite annoying [laughs]',* noting that *'people treat you like an invalid,'* and multiple people mentioning, in response to these sorts of treatments, *'It's not an illness.'* Some respondents highlighted that, in contrast to pregnancy being a state of weakness, it's actually an incredible feat of the human body, and labour especially requires strength and fitness to be maintained throughout pregnancy in order to cope with the rigours:

This whole idea that it's, pregnancy makes you weak-- actually it's one of the strongest things, you know, going through labour is one of the hardest things you're ever gonna do. You need to be strong and fit to do that and you're not gonna get that from putting your feet up and having a cup of tea and a slice of cake. Michelle, 35, second pregnancy

7.3.2.2 Discouragement of physical activity

In addition to the encouragement to sit down and rest, almost all respondents described receiving disapproving comments from other people concerning their physical activity during their pregnancies. Such comments were not confined to the late stages of pregnancy, but seemed to begin as soon as others knew of the women's pregnancy status, either due to verbal disclosure or due to the visibility of the bump. These remarks primarily came from people embedded within the women's everyday lives, including partners/husbands, parents, parents-in-law, co-workers, bosses, and

midwives, with some comments coming from more distant individuals such as gym staff and complete strangers. These comments were not confined to exercise or high-intensity activity; a number of women described being '*told off*' for engaging in particular everyday physical behaviours, such as carrying their infants or toddlers, for moving boxes or furniture around at home or work, for climbing stairs, for cleaning their houses, and even for standing or walking around. This experience was summarised by one participant as:

> *'Oh don't lift anything, don't move anything, oh you can't do that'…Everyone says, 'Oh, you can't do that 'cause you're pregnant! Oh, you can't do that 'cause you're pregnant!'* Michelle, 35, second pregnancy

While remarks were made in relation to everyday physical activity, activities classed as moderate-to-vigorous intensity, such as boot-camp classes or weight-lifting at the gym, were the subjects of the most intense scrutiny. Two participants described this in detail:

> *I signed up to a kind of boot-camp type thing that I'd been training at. I'd trained with them for about six months and had a great relationship with the instructor… and found out I was pregnant and obviously mentioned it to her 'cause I was like, 'Just so you're aware, I'm pregnant. Obviously, I'll need to just tone down'…and unfortunately, whilst that instructor was incredibly supportive, was like, 'Absolutely fine, we'll adapt, we'll adjust things,' and she was trained in pre- and post-natal stuff, the other instructor who actually owned the business turned around and went, 'Absolutely not, you can't train with us anymore… you're pregnant and it's a danger to yourself if you continue to train in this way.'* Michelle, 35, second pregnancy

> *That's the one thing that worries me at the gym-- if someone's looking at me, I wanna say, 'I know what I'm doing. I've been trained. I'm not doing anything crazy and I'm doing what's right.' You wanna have like a big sign, don't you: 'I'm doing what's right for my baby.'* Kathryn, 34, first pregnancy

It should be noted that while the overarching theme was that physical activity during pregnancy was discouraged by others, there were instances in which physical

activity was encouraged, admired, or expected, suggesting that there is variation in how others respond to activity during pregnancy:

> *Me husband-- I would say he still thinks that I'm gonna climb up chairs and fix the bathroom fan and things like that which he asked us to do last week... When he was at work the other day, I moved all the furniture in the baby's room around on me own, like just dragging them, and he wasn't bothered by it. I got wrong off his mam but him, he was just like, 'Ah yeah, that's good' [laughs]* Bethany, 27, first pregnancy

> *Well a lot of positive [responses to maintaining activity during pregnancy]. A lot of, 'God, I can't believe you're doing that. I can't believe you're so dedicated.'* Julie, 40, fourth pregnancy

> *I still try and take the dog out, but it's kind of got to like once a week. Me husband's been doing that, and it's got to the point now where he'll go, 'Come on, get up, we're going out for a walk.'* Bethany, 27, first pregnancy

7.3.3 Negotiating the conflict between social expectations, personal capability, and the demands of everyday life

When asked how they interpreted encouragement to sit or discouragement from activity, respondents said it was just *'friendly advice,' 'concern',* and protection. However, participants were quick to point out that they generally disagreed with others' assessments of what their activity and rest patterns ought to be. Rather, they highlighted that, while pregnancy does entail a range of constraints on physical function (e.g., tiredness, sickness, trouble with hips and joints), which affected each of them at various time-points during their pregnancies, these physical limitations and their effects are highly variable and depend upon the person, the trimester, and the pregnancy:

> *There are different people who experience different things in pregnancy. I've been very fit and healthy during my pregnancy. I haven't suffered a lot of aches and pains. I felt strong throughout. Now, not everyone has that kind of pregnancy and I fully appreciate that.* Michelle, 35, second pregnancy

I just think, as I said-- it's best to just keep going and doing as much as you can. If something does hit you, like in pregnancy, then you might not be able to do many things, so I think whilst you can do them, you should do them. Shannon, 37, second pregnancy

I was one of these people that wanted to exercise all through pregnancy 'cause I know it's beneficial, good for you, and when I physically couldn't I just-- I had no energy…I was quite frustrated in my first trimester when I couldn't and then-- to the point where I was like almost wanting to slap myself across the face going, 'Come on, get over it, get in there.' And I just physically couldn't, and that was weird. Natalie, 39, first pregnancy

Participants indicated that, since experiences during pregnancy are so variable, others' seemingly universal expectations for what pregnant women should (not) or can(not) do solely because they were pregnant were inappropriate. Instead, most women pointed to the importance of listening to their own bodies to determine their limits and to know when or whether they need to rest:

As long as you're comfortable, do what you want really. That's what I would say. You know your own body. It'll tell you when it's had enough. Kelly, 33, first pregnancy

Your body knows. It'll tell you to stop. You just gotta listen to your body. Leanne, 35, second pregnancy

Thus, there is a clear conflict between a social expectation for pregnant women to slow down and women's expectations of themselves to do whatever they felt able, which was generally much more than others expected of them. This conflict was generally negotiated in physical activity practices through three pathways. Most commonly, women reported simply rejecting the comments that were being made to them by '*just say[ing] 'whatever''* or '*knock[ing] it off to a degree*,' particularly if the criticism was coming from their partners/husbands. They described simply carrying on with whatever it was that provoked the comment in the first place:

Respondent: *I was scrubbing toilets and baths out and stuff and I was getting wrong for that.*

Interviewer: *So what-- did you keep doing it or--*

Respondent: *Well it was only for one day so, I just did it anyway.* Nicola, 32, second pregnancy

My dad, he will wrap me in cotton wool. 'I'll do this. No, no, no, no, don't do that.' I wanted to do some painting in the house and he came round and he was like, 'I'll do it, I'll do it all,' and I was like, 'Dad, I'll do what I can do, you do the rest. You start on that side, and I'll start this side.' Jessica, 34, first pregnancy

Less commonly, women reported complying with the restrictions placed on them. Their compliance was not necessarily because they agreed with the restrictions, but was often simply because they were *'sick of [getting] told off'* for doing activities. The third, more complex response to others' comments was a surreptitious negotiation, in which women carried on with the activities under criticism out of view of the criticiser. One woman, for example, described being told by her husband that she ought to be resting all the time and refraining from doing any household tasks. In response, she secretly continued her household tasks when he was out of the house:

Well [husband] was cutting the grass on Saturday and then I kept looking to see where he was and kept doing little things and then sneaking to do something and then coming back to the sofa [laughs]. 'What are you doing?' 'Oh, I'm just, I'm drying my hands.' 'Drying your hands?' 'Oh, they weren't quite dry from before.' Sarah, 34, first pregnancy

Similarly, two women shared their independent experiences of attending personal weight-training sessions that were held at (female) trainers' houses (not the same trainer) in order to avoid the disapproval that came from others at the gym:

I go to this [female personal trainer]. It's at her house, so it's quite nice 'cause it's not like everyone's looking at you and going, 'Oh my god, there's a big bump!'…I've just been going to her rather than doing it in the gym. Kathryn, 34, first pregnancy

I ended up signing up to do some personal training with an instructor who specializes in pre- and post-natal…it's in her house but she runs sessions small group sessions so some of the sessions were just me and the personal trainer and some of the sessions were me and other people…I've trained with a couple of other pregnant ladies or sometimes it was just other

women, it's always women…I don't think I'd have kept training had I not had that, I'd have been like, 'No, I'm not going to the gym anymore. I've had enough,' because you are aware of people looking going, 'Ohhh,' kind of going [demonstrates judgmental glance]…you don't feel comfortable in that environment. Michelle, 35, second pregnancy

They described this environment as much more welcoming and they felt freer to engage in the activities that they felt appropriate for their bodies without having to face public disapproval.

In addition to conflicts between others' expectations and their perceived capability, another conflict they described negotiating was between others' expectations and the demands of their everyday lives. There was a general rejection of the overall expectation for women to do nothing throughout their pregnancy because the roles and activities within women's everyday lives were incompatible with sitting around and refraining from physical exertion. They contrasted their pregnancies today with pregnancies in the past, including when their mothers or older co-workers were pregnant, in which their social roles at that time did not (according to interviewees) demand them to work in the same way as in the present:

The main thing they [colleagues] say to me is, 'Take it easy'…I think it's probably just from the past, really, when women were more-- like some of the women I work with, I work with a lot of like older women, and they had to finish at a certain time for their maternity leave and things like that and like, you should put your feet up and try and do less, but I don't think that's the case anymore. We work right up until we have the baby and things like that so I don't think-- I think it's just in their instinct to tell you what they've been through and their experiences because they're all a little bit older. Obviously, things have changed in the last 20 years. Shannon, 37, second pregnancy

In contrast, women in this sample identified that, in the modern era, they (and women more generally) are required to balance social roles of economic provider (all women in this sample were employed at least part time) and domestic caretaker, which encompasses household duties and caring for children among those who had any. Furthermore, these women noted that each of their social roles require at least

some degree of physical activity, creating a conflict between what they needed to do in everyday life with what they were expected to do, or expected not to do:

> *I get told an awful lot off older people for just, you know, standing or walking or picking [son] up, which I know like he's heavier than what I'm allowed to pick up, but he's my son and he needs picking up sometimes. What am I gonna do?* Nicola, 32, second pregnancy

> *When you've got, you know, people say, 'Oh you can't lift that.' Well, what do you do if you've got a toddler? Do you not lift him? Do you not help them do things, do you not bend over, do you not assist him to get dressed and all that kind of stuff?* Michelle, 35, second pregnancy

> *Gotta get on with it. A two-year-old's not gonna look after himself.* Molly, 28, second pregnancy

> *[At work] I'm still doing more lifting than I probably should, but in a pub when it's busy, sometimes it's impossible to wait for someone else to become free, like the glass trays have to be pulled out of the machine or put in, and on a busy shift I just grit my teeth and do it.* Jessica, 34, first pregnancy

Furthermore, women mentioned thinking ahead to the postpartum period and wanting to maintain enough strength and fitness to manage caring for their new-born while also managing the rest of their lives:

> *People don't encourage you to do exercise sometimes, things like not pick up [daughter] and things like that. I'm like well, I'm always gonna have to do that 'cause when the baby comes, I still need those muscles to be able to pick her up, and gotta play with her and stuff like that… It's modern life, people have to get on with it. Like I say, lifting things, carrying bags, things like that, but at the end of the day, [daughter]'s two stone. I've got muscles that need to be kept going. I can't just sit and go [slumps], 'cause at the end of the day [partner] will be off work for three weeks when the new baby comes and after that I've then got to travel around with bags, car seats, [daughter], toys, whatever, and it's gonna be a lot more than what I had with [daughter] when you just had one child.* Leanne, 35, second pregnancy

It should be clarified that participants did make adjustments to the physical activity necessitated by their social roles in accordance with how they felt, when it became necessary. For example, some women went on maternity leave early to manage extreme tiredness in the third trimester, and many participants mentioned delegating household activities, childcare, or work activities to others when they felt they were physically unable. However, as far as they felt capable of continuing to do what they normally did, respondents felt that the physical activity restrictions imposed upon them by others were not compatible with the everyday roles that they were expected to perform. This tension was highlighted particularly well by one participant who pointed out that pregnant women are expected to do nothing and everything at the same time:

> *It's almost like society's kind of got it wrong, in that like they cocoon you in one sense, and then expect them just to carry on in another*. Michelle, 35, second pregnancy

7.3.4 Negotiating gestational diabetes risk: 'It is what it is'

As each of these women had a risk factor for gestational diabetes, their understandings of what it meant to be 'at risk' and any possible linkages between their risk status and physical activity practices were explored.

Overall, women seemed to conceptualise their 'risk' of developing GDM to be almost directly linked to body mass:

> *I was worried when they did the glucose test, but because I'd lost weight in the first trimester, it sort of relaxed us a little bit because I knew I wasn't as bad as what I was originally when they first weighed us…that made us feel a lot better that I managed to keep the weight off, which obviously lowered my risk anyway…Because I'd lost the weight I felt a little bit better.* Bethany, 27, first pregnancy

> *I've put on more weight with being pregnant as well. That might make you be more prone to getting it [gestational diabetes] maybe. I can't remember anyone ever giving us any explanation, just it was more like, 'You've got a higher BMI so you're at higher risk of getting it.'* Shannon, 37, second pregnancy

While some, particularly those who had a family history of diabetes, mentioned their awareness that if it runs in the family they might be more likely to get it, many pointed to their weight as a direct indicator of whether they were 'actually' at risk:

> *I was tested was because my grandma and granddad were type 2 [diabetic] and my dad I think was type 1, so as soon as I told them that, they were like, 'Yeah, we'll test you.' No one ever thought I would actually have it, you know, I'm not a big girl or anything like that, and yeah I had it [gestational diabetes].* Kelly, 33, first pregnancy

This notion of weight predicting risk led to a general attitude of 'it is what it is' in relation to gestational diabetes risk. Most felt that their weight was not modifiable, especially those who had tried for years to lose weight unsuccessfully, and perceived that most pregnancy weight gain was '*the bump*,' so pregnancy was not the time to try to modify body weight ('*It's like too late to do anything really about it [my weight], you know?'* Shannon, 37, second pregnancy). Thus, whatever their body weight was at the time they were pregnant determined how likely they were to develop gestational diabetes.

When asked if learning of their 'risk' status had any influence on their lifestyles, most said it did not because, as described above, their weight determined their risk and their weight was not modifiable during pregnancy. However, a few women mentioned lifestyle modifications in the period between being told they were 'at risk' (usually around 8-10 weeks' gestation) and having their glucose tolerance test (usually 24-28 weeks' gestation). Most commonly, these modifications were focused on diet, especially reducing sugar intake:

> Interviewer*: Did being told that you were at risk for gestational diabetes affect how you did things between then and then when you had the test?*
>
> Respondent*: I think at first it did, if I'm completely honest, I think at first it did. I was like a little concerned thinking, 'Right, I'd better be careful with the sugar now and maybe for a little while.'* Natalie, 39, first pregnancy

Physical activity patterns generally went unchanged in response to GDM risk, although a couple of women mentioned that their risk status motivated them to continue the exercise they were already doing:

Interviewer*: Did that [learning of your gestational diabetes risk] have any impact on your lifestyle at all?*

Respondent*: I think it definitely drove me to keep exercising. I don't even know if there's anything that even says that exercise prevents gestational diabetes… I think I'm probably more conscious around diet and exercise as a result than I would have been had I not been at risk, if that makes sense.* Michelle, 35, second pregnancy

I think because I've always done everything I can to improve and maintain activity, I don't think I do anything differently because I'm at risk, no. Julie, 40, fourth pregnancy

I was maybe a little bit more mindful of like-- that was probably one of the reasons, extra reasons, I don't think I would change my mind and I would suddenly just stop doing like aqua-natal classes, but I think it was an extra encouragement to do more rather than-- because, you know, diet is more difficult than moving about probably. Paige, 33, first pregnancy

Four women in the interview sample were diagnosed with gestational diabetes in this pregnancy; for two women, this was the second time they had been diagnosed with gestational diabetes (both second pregnancies), and for two others, this was their first diagnosis (one first pregnancy and one second pregnancy). All four participants had slightly different reactions to being diagnosed with gestational diabetes in this pregnancy, although three pointed to concern for their unborn babies as a key worry:

I think the only thing that worried us about is when they were talking about how she would get all the sugar so she could end up being really big, and obviously that has loads of different impacts so that I didn't know that side of it. I thought it was just impact on me, not her. Kelly, 33, first pregnancy

Additionally, two participants described feeling disheartened by their diagnoses of gestational diabetes because the diagnosis came despite their best efforts to prevent it:

Interviewer: *So how did you feel when you were diagnosed?*

Respondent: *A failure. You just—you're doing all you can for this baby and making sure they're safe, you know, and don't drink alcohol the minute I found out I was pregnant. I've never smoked, and you're doing all these things to make sure that, you know, you're following the guidelines, so to speak, to bring this baby in safely and it's sort of like, well, it doesn't really matter what you're doing because you're overweight. You're kind of putting them at risk, type thing, so it was, it's a hard pill to swallow.*
Rachel, 26, second pregnancy

Respondent: *I wasn't annoyed or anything but it's a bit to get your head around, 'cause I was like, I haven't done anything wrong. You know, I don't eat a lot of sweets and stuff like that. I'm not really a sweet tooth.*
Nicola, 32, second pregnancy

Being diagnosed with gestational diabetes did not appear to have a direct impact on physical activity. Two respondents described the continuation of their physical activity routines (walks at weekends and walking the dogs) following their diagnoses, although only one of these respondents explicitly linked her physical activity routine to being told by her midwife that exercise helps to manage gestational diabetes. The third respondent recalled being told to exercise more to aid diabetes management, but cited her concurrent symphysis pubis dysfunction (SPD) as a major hindrance in her ability to move around much. Finally, the fourth participant did not recall being told anything by midwives or consultants about physical activity in relation to gestational diabetes management and seemed content to continue her everyday physical activities.

7.4 Discussion

This chapter aimed to explore and highlight the social context of sedentary time and physical activity practices during pregnancy. Additionally, this chapter aimed to understand how women conceptualised being 'at-risk' for gestational diabetes and whether their risk status influenced their physical activity practices during pregnancy. These are discussed in turn below.

7.4.1 Social expectation to slow down during pregnancy

In general, participants in this study felt or experienced an expectation from other people to slow down during their pregnancies. This manifested as both being encouraged to sit down and rest (sedentary time) as well as being discouraged from all forms of physical activity. This social expectation to sit and slow down was not in response to how women were physically feeling at a given time, but was an overarching expectation linked to their pregnant statuses.

To my knowledge, this is the first study to highlight the social context of sedentary time during pregnancy and the first to describe how central it is to women's experiences of pregnancy and how it often conflicts with how women feel at a given time. However, this study is not the first to describe women being told by other people to rest because they were pregnant. This phenomenon is mentioned in passing within other studies within and beyond the physical activity literature. For example, in interviews aimed at understanding obese women's experiences of pregnancy in the UK, Heslehurst et al. (2015) quoted a participant who described family as a barrier to physical activity, saying *'I hate sitting round, I've got to be up all the time, I'm getting wronged off him [husband] for it. 'You're not sleeping enough, sit down, you do this, you do that', and I'm like (rolls eyes)'* (p. 974). A similar quotation appeared in Evenson's (2009) focus groups describing interpersonal barriers to physical activity: '*I have decreased my physical activities. I don't do much of anything. My husband doesn't let me do much. He thinks that if I lay down, the baby will be fine'* (p. 7). Through interviews aiming to understand physical activity engagement during pregnancy, both Flannery (2018) and Denison (2015) identified themes in which other people served as 'barriers' to physical activity. Flannery et al. (2018) quoted one participant saying, *''Put your feet up' that's what I get especially over the last four weeks, from my mother in law'* (p. 9). A participant quoted by Denison et al. (2015) shared a similar sentiment: *'A lot of people have constantly said to me throughout my pregnancy, you need to rest, you need to rest, you need to rest. I don't really understand why I need to rest. If my body's not telling me that I need to rest, you know, then why do I need to rest?* (p. 1165).

This experience also appears in non-physical activity literature. In Ann Oakley's (1979) interviews with women in London during their pregnancies, in response to

the question of whether they thought pregnancy was a medical condition, a respondent described being treated as fragile and being told to put her feet up and rest. In Robin Longhurst's (1999) ethnographic study of pregnancy in New Zealand as a rite of passage and the advice that comes along with it, she describes: *'a third example of advice that pregnant women often receive from colleagues, as well as from friends, family members and loved ones, is to rest and sit or lie down as much as possible, to not 'overdo things', to not lift anything heavy or stretch and bend too vigorously and to not partake in some sports such as running, skiing, diving and horseback riding'* (p. 81). However, despite this seemingly ubiquitous expectation for women to sit and rest when they are pregnant, including within the physical activity literature, it has been mentioned as an aside to the main focuses of the papers, rather than being treated as central phenomena of women's experiences during pregnancy.

In addition to being encouraged to sit down and rest, women in this sample also reported being discouraged from engaging in physical activity during their pregnancies. In other studies aiming to explore factors that influence physical activity during pregnancy using qualitative methods (primarily interviews and focus groups), a range of 'external barriers' to physical activity within their home environments have been identified, often family and friends dissuading women from activity; (Denison et al., 2015, Evenson et al., 2009, Weir et al., 2010) as well as unsolicited and unwanted advice and comments from other people about their activity (Cioffi et al., 2010). As with resting (as described above), this study is not the first to identify a social expectation to reduce physical activity, but is among the first to describe how central this phenomenon is to women's experiences during their pregnancies and how this expectation often overrides what women want or need to do in everyday life. To my knowledge, the only other study that has examined this phenomenon in-depth is van Mulken et al. (2016) who described (using interview data in Australia and a feminist standpoint approach) a dominant social expectation to reduce physical activity during pregnancy to protect the foetus. Despite the strong influence that social expectations have on women's physical activity during pregnancy, the majority of physical activity research during pregnancy has focused on 'intra-personal barriers' (Coll et al., 2016); however, such a focus may have limited efficacy if the broader public is unaccepting of physical activity during pregnancy.

It is important to note that while a key theme of this chapter and the literature cited within this discussion emphasises a social expectation to reduce physical activity, this is not necessarily universal and not necessarily always in conflict with women's physical status at a given time. For example, within this study, there were some instances of being encouraged to be or remain active, which is consistent with mentions within other studies that have been previously described of partners or family members encouraging or supporting physical activity during pregnancy (Weir et al., 2010, Denison et al., 2015, Flannery et al., 2018, Cioffi et al., 2010). There were also instances of women describing needing to sit down and rest because they felt tired, which aligns with other studies commenting on intrapersonal barriers to physical activity (Coll et al., 2016). However, external expectations were not specific or responsive to feelings at given times but were applied more universally.

The origin of this social expectation for women to sit down and reduce physical activity during pregnancy is not explicitly clear. However, as described in the literature review (see section 2.9), pregnant bodies have long been under surveillance for the sake of protecting and cocooning the 'fragile' foetus (Lupton, 2012). Physical activity during pregnancy has been conceptually associated with posing a risk to the foetus (van Mulken et al., 2016, Evenson et al., 2009, Clarke and Gross, 2004), and thereby may violate the expectation of what a 'good mother' (who protects the foetus from all possible risks) 'should' do (Lee, 2008, Burton-Jeangros, 2011). Thus, it may be that encouragement to sit and rest is simply an extension of this, and that 'doing nothing' is perceived as the lowest-risk state for the foetus.

Partners were commonly identified as 'restrictors' of physical activity in this sample, although it is important to note that this was not necessarily true for all participants. Other studies have similarly reported mixed findings, with some indicating that partners discouraged physical activity (Evenson et al., 2009) and others indicating that partners encouraged physical activity during pregnancy (Weir et al., 2010, Flannery et al., 2018, Harrison et al., 2018, Denison et al., 2015). The involvement of partners in physical activity practices during pregnancy may reflect a broader pattern in which partners aim to do what they can to reduce the risks of adverse

outcomes for both their partners and unborn babies[35] (Steen et al., 2012), potentially by attempting to regulate their partners' 'risky' behaviours. For example, partners have been shown to actively dissuade their partners from drinking alcohol and eating 'risky' foods during their pregnancies (Burton-Jeangros, 2011), or from consuming sugary foods for women diagnosed with gestational diabetes (Evans and O'Brien, 2005). As partners often seek out information during their partners' pregnancies as a way of showing support or gaining involvement (Steen et al., 2012, Finnbogadottir et al., 2003), it may be that partners either discourage or encourage physical activity based on the contents of the information that they read or hear. Given the inconsistencies in information concerning physical activity during pregnancy across sources (Weir et al., 2010, Reid et al., 2017), it is unsurprising that partners (as well as pregnant women themselves) may come to a range of conclusions concerning the importance or safety of physical activity during pregnancy.

In response to social disapproval of physical activity during pregnancy, participants in this sample responded by complying, rejecting what others were saying, or surreptitiously negotiating their activities by carrying on with their activities privately. Similar types of responses have been documented for women's responses to smoking during pregnancy (Flemming et al., 2013). This range of responses is consistent with evidence suggesting that pregnant women, and adults more broadly, actively negotiate biomedical norms and public health messages in relation to their own experiences, circumstances, and embodied knowledge, resulting in a spectrum of practices ranging between absolute compliance with biomedical norms and absolute resistance to biomedical norms (Root and Browner, 2001). It is worth pointing out here that, in the case of physical activity during pregnancy, exactly what the biomedical norms are has never been clear. Indeed, advice from midwives and other health care practitioners concerning physical activity during pregnancy, as well as physical activity guidelines themselves, have often been regarded as vague (Weir et al., 2010, Padmanabhan et al., 2015) and particularly focused on restrictions (Padmanabhan et al., 2015, Stengel et al., 2012), perhaps reflecting a broader phenomenon in which biomedical uncertainty may be interpreted as danger, making

[35] The term 'baby' is contentious in this context, but is used in the studies cited here, so I have used the term to keep the terminology consistent

abstinence the 'risk-averse' option (Lowe and Lee, 2010). This may mean that women may more heavily rely upon their embodied knowledge to fill in the gaps, and how they negotiate conflicts between their embodied knowledge and biomedical (or social) expectations may be negotiated in temporally and contextually specific ways.

The participants in this sample had surprisingly positive perceptions surrounding physical activity during pregnancy. While some participants mentioned certain activities they would not do while pregnant due to safety concerns, there seemed to be very little uncertainty about whether physical activity was safe for the foetus (this may reflect biases within the sample; see 'Strengths and limitations' for discussion). This contrasts with many other studies that have described women's concerns about the safety of physical activity during pregnancy, particularly for the foetus' wellbeing (Padmanabhan et al., 2015, Evenson et al., 2009, Coll et al., 2016, Harrison et al., 2018, Denison et al., 2015, Connelly et al., 2015, Flannery et al., 2018). This positive attitude toward activity during pregnancy may be related to the information that they receive because of their 'high-risk' status, particularly in relation to high BMI. For example, the NICE guidelines for antenatal care for women with a BMI ≥30 indicate that exercise should be *encouraged* by health care practitioners to help regulate weight; this contrasts with the NICE guidelines for 'uncomplicated' pregnancies, which simply indicate that exercise *is not harmful* (National Institute for Health and Care Excellence, 2008, National Institute for Health and Care Excellence, 2010). Although advice from health care practitioners about physical activity is often described by pregnant women (including obese women) as vague (Padmanabhan et al., 2015, Weir et al., 2010), limited (Ferrari et al., 2013, Flannery et al., 2018), or focused on restrictions (i.e., on what you should *not* do rather than on what you should do) (Padmanabhan et al., 2015, Stengel et al., 2012), there is also evidence that health care professionals emphasise the importance of physical activity during pregnancy in relation to weight control (Duthie et al., 2013). Thus, it may be that advice and dialogue surrounding physical activity between participants and their health care providers in this sample may have been particularly favourable toward physical activity.

7.4.2 Negotiating gestational diabetes risk

To my knowledge, this is the first study to date to examine what it means to pregnant women to be 'at risk' for gestational diabetes. The only other study that has

addressed this quantitatively measured how women in Australia who were at risk for GDM (based on similar but not identical risk criteria as the participants in this study[36]) perceived their risk; half of respondents did not think they were at increased risk for GDM, and 33% thought their risk was only slight (Harrison et al., 2012). No other studies have explored how risk of GDM is conceptualised and whether it influences physical activity practices.

In this sample, a key theme was that the degree of one's perceived risk for GDM was directly linked to their BMI. This perception is consistent with a prevalent public assumption that obesity is a direct cause of type 2 diabetes (McNaughton, 2013). In general, the conceptual link between both gestational and type 2 diabetes and obesity reflects broader obesity discourses in which obesity is described as an 'epidemic' by both professionals and lay people and is implicated as a key contributing factor to a number of poor health outcomes (Lupton, 2013, Gard and Wright, 2005). Because 'risk' was conceptually linked to BMI in this sample, learning of 'risk' seemed to have little effect on physical activity during pregnancy because it was seen to be less relevant than their weight, which they felt they could not change during pregnancy.

The general responses to being diagnosed with gestational diabetes among women in this sample were feelings of guilt, confusion, and concern for the baby's wellbeing. One participant explicitly linked her feeling of guilt to her BMI, indicating that it was her weight that was putting her baby at risk. This reflects a broader medical and public perception in which (obese) women are conceptualised as personally responsible for the 'effect' that their obesity could have on the foetus, either in the short term (e.g., foetal size) or long term (e.g., childhood obesity) (Warin et al., 2012, Warin et al., 2011, McNaughton, 2011).

7.5 Strengths and limitations

The main strength of this chapter's findings is the use of qualitative methods (semi-structured interviews) that allowed the flexibility to explore various aspects of

[36] Specific 'risk' criteria in Harrison et al. (2012) included previous GDM, 'maternal age' (no cutoff provided), 'increased BMI' (no cutoff provided), first degree history of type 2 diabetes, or high-risk ethnicity group. These are generally similar to the risk criteria for the participants in this study, except that age was not considered a risk factor in this study, while fetal macrosomia was. Additionally, the criteria included in this study specified a BMI cutoff of 30 kg/m^2

women's experiences of pregnancy. The data concerning 'resting' and physical activity are strengthened by the fact that neither of these topics were explicitly on the interview schedule; rather, discussions around these issues emerged organically.

This chapter also has a number of limitations which must be taken in to consideration when interpreting the findings. First, because the interviews took place within the broader study (which the participants knew was about physical activity), the participants who were interested in being interviewed may have had particularly positive views in relation to physical activity. However, it is worth noting that, as shown in Table 7.1, the interview sample was not 'more active' than the broader study sample.

Second, it is possible that my affiliation with the hospitals from which participants were recruited and my role as a physical activity researcher in the project may have had an impact on what participants shared in the interview. I told all participants that I was not a health care professional and that the purpose of the interviews was to learn more about their experiences and ideas, for which there were no 'right' or 'wrong' answers; however, it is still possible that my role influenced their responses.

Third, as this was my PhD study, I undertook all of the interviews and the qualitative data analysis on my own. Having a second researcher independently code the transcripts or review my coding strategy would have helped to minimise my biases and improve the rigour of the analyses. However, as deep familiarity with the data is a critical first step in qualitative data analysis (King and Horrocks, 2010), my involvement in both the interviews and their analyses can also be seen as an advantage since I was closer to the data than any second researcher would have been.

Fourth, following on the previous point, while it would have been ideal to verify the findings and themes of this chapter by checking my interpretations and findings with participants themselves, this was not feasible in the study's timescale and was beyond the limits of participants' activities based on what was agreed upon with NHS ethics.

Fifth, my identity and attitudes in relation to physical activity and their impact on the collection and interpretation of the data must be acknowledged. I have a deep-seated, long-standing personal interest in physical activity, particularly of an extreme and vigorous variety (for example, I trained for and ran my 24th marathon during fieldwork while also taking part in CrossFit on a near-daily basis). While I never discussed my physical activity practices with interview participants, it is possible that my fitness was evident on my body, which may have prompted participants to talk more favourably about their own physical activity practices in efforts to please me. My personal (and academic) interest and views concerning physical activity may also have impacted my analysis, for example by unintentionally zeroing in on what participants said about physical activity and potentially giving less attention to other things they talked about that were important to them.

Finally, in another reflexive point, I am a staunch feminist who believes very strongly in giving voice to women's experiences, with a sometimes not-so-subtle intention of pushing back against biomedical research that has reduced the social, political, and biological complexities of women's everyday lives to discrete categories and calculable variables. While this is not necessarily a limitation (indeed, entire fields of study are populated with researchers achieving the same aims), it is worth acknowledging that my personal position as a woman and as a feminist likely influenced how I interpreted and analysed the experiences that the interviewees shared with me (though, arguably, for the better).

7.6 Conclusions

The findings presented in this chapter suggested that there is a social expectation for women to slow down during their pregnancies, by sitting more and/or moving less, and this expectation was detached from women's own perceptions and capabilities. These findings reflect broader literature that details the social construction of pregnancy as a time in which the fragile foetus must be protected, and reflect the lay uncertainty about the 'goodness' of physical activity during pregnancy. This may have implications for how information about physical activity during pregnancy is communicated; partners, family members, and the broader public – not just pregnant women - should receive information about of the safety (and benefits) of physical activity during pregnancy. However, given the deep-seated social perception of the vulnerable, 'at-risk' foetus (and the associated 'meaning' of

physical activity during pregnancy in relation to the foetus; see section 2.9), simply informing people is unlikely to be a simple or effective solution.

These findings also have implications for the design of any interventions that are aimed at increasing physical activity or minimising sedentary time during pregnancy. Without targeting broader social understandings and attitudes concerning activity levels during pregnancy, interventions are especially unlikely to be successful. Furthermore, interventions need to fit into everyday life and ongoing 'life projects' to be effective (Carpenter, 2013); supporting women to incorporate physical activity into their lives in ways that work best for them may be a way forward. Interventions may also benefit from considering physical activity and sedentary time (during pregnancy) as social practices (Blue et al., 2016). This approach, while certainly challenging to practically implement, would redirect the focus away from targeting 'behaviour change' at the individual level and would prioritise identifying ways in which the elements of the practices themselves (materials, competence, and meanings) might be modifiable on a broader level.

In relation to gestational diabetes risk, the findings in this chapter indicated that women perceived their risk of GDM as directly proportional to their weight. Some, but not all, tried to reduce their risk in the period between learning of their risk status and having the glucose test through decreasing sugar consumption or increasing physical activity. This has implications for how risk factors for gestational diabetes are communicated, primarily in maternity care but also in wider public health campaigns. Not only does the 'obesity discourse' result in 'normal weight' women being blindsided by GDM diagnoses because they 'didn't think they would actually get it,' but it also perpetuates the stigmatisation of obesity during pregnancy, when women are held personally culpable for their diabetes simply because of their size. A better way forward may be to place less emphasis on 'weight' and 'BMI' and to facilitate physical activity during pregnancy in ways that fit within women's lives.

Chapter Eight: Conclusion

In this concluding chapter, the main findings of the study are summarised and the strengths and limitations of the study are identified. The ways in which this thesis contributes to knowledge are highlighted, implications of the findings are discussed, and directions for future research are identified.

8.1 Review of the main study aims and findings

8.1.1 Sedentary time/behaviours, gestational diabetes, and glucose levels

The primary objective of this thesis was to test the hypothesis that total sedentary time would be associated with the development of gestational diabetes (GDM) and glucose levels among women with a risk factor for GDM. It was also hypothesised that different aspects of sedentary time/behaviour (objective, television time, occupational sitting time) would have different associations with GDM and glucose levels. The following paragraphs discuss the findings of different aspects of sedentary time in relation to GDM and glucose levels before summarising the findings all together.

Total sedentary time as measured by the activPAL accelerometer in the second trimester of pregnancy was associated with fasting and 2-hour glucose levels. However, this association depended upon GDM status; total sedentary time positively predicted glucose levels among those without GDM, but was not associated with glucose levels among those with GDM (Tables 6.4 and 6.5, pages 151-152). The association between sedentary time and glucose levels has been repeatedly documented in adult populations (Powell et al., 2018, Brocklebank et al., 2015), but to date, this is the first study to report an association between sedentary time and glucose levels during pregnancy. The detection of this association in this sample is likely attributable, at least in part, to two key methodological strengths: the use of an accelerometer than can accurately detect posture (which is a key distinction in the measurement of sedentary time), and the application of interaction terms in the statistical models which may have uncovered the effects of sedentary time on glucose regulation among those who do not have pathological glucose regulation.

While total sedentary time was linearly associated with both fasting and 2-hour glucose levels (among those who did not have GDM), total sedentary time was not associated with development of GDM. The effect size of the association between sedentary time and GDM was effectively zero (OR 1.003 (95%CI 0.998, 1.008)). It is possible that while sedentary time does appear to have an impact on glucose levels (among those without GDM), its effect in the actual pathophysiology of incident gestational diabetes may be negligible, perhaps due to the upper limit on how much time one can possibly spend sedentary per day.

The effects of the distribution of objectively measured sedentary time, operationalised as prolonged sedentary time (time spent in uninterrupted sedentary bouts lasting at least 30 minutes) and breaks in sedentary time (number of sit-to-stand transitions per day), were also tested in relation to glucose levels and GDM. Prolonged sedentary time was positively associated with fasting glucose, regardless of GDM status, and its effect size was comparable to that of total sedentary time for those without GDM (Table 6.11, page 155). Breaks in sedentary time were associated with lower glucose levels (both fasting and 2-hour); however, while it was expected that breaks in sedentary time would be beneficial for the entire sample, the impact of breaks on glucose levels were only seen among those with GDM (Tables 6.13, 6.14, pages 158-159). This fits within recent research findings suggesting that breaking up sedentary time may be especially beneficial for those with impaired glucose metabolism or low cardiorespiratory fitness (McCarthy et al., 2017, Dempsey et al., 2018, Paing et al., 2018). Taken together, the findings of prolonged sedentary time and breaks in sedentary time suggest that, beyond how much time is spent sedentary on a given day, the way in which sedentary time is accumulated may have an additional impact. This is the first study to examine the effects of prolonged sedentary time and breaks in sedentary time during pregnancy, although the effects of prolonged sedentary time and breaks in sedentary time among the general adult population, in both laboratory (Dunstan et al., 2012a, Henson et al., 2016, Chastin et al., 2015a) and free-living studies (Healy et al., 2008a, Carson et al., 2014, Sardinha et al., 2017, Healy et al., 2011b), have previously been demonstrated.

In the compositional models, sedentary time had no association with incident GDM or glucose levels (Tables 6.15, 6.16, 6.17, pages 161-162). Given the sparse literature that has examined compositional effects on biomarkers, it is unclear what these null

results might mean. The field of physical activity research ought to continue to apply compositional models to further understanding of how 24-hour time use collectively influences health outcomes and associated biomarkers.

In this study, television time (which was dichotomised as less than or at least 2 hours per day) in the second trimester was associated with increased risk of gestational diabetes (Table 6.23, page 165). Furthermore, the effect size of the association between television time and GDM (OR 3.03 (95%CI 1.21, 7.96)) was much larger than that of total sedentary time, which confirms the hypothesis that the effect of television time would be larger. Television time has repeatedly been associated with type 2 diabetes risk (Wilmot et al., 2012, Biswas et al., 2015, Grontved and Hu, 2011), and its effect has been suggested to be larger than that of total sitting time (Patterson et al., 2018), thus the result of this study is consistent with this pattern. It is worth noting that while television time was associated with incident gestational diabetes, it was not associated with glucose levels. This study is not the first to test an association between television time and GDM (Gollenberg et al., 2010, Oken et al., 2006, Padmapriya et al., 2017), but is the first to report an association. This may be due to the fact that this was a high-risk group.

It was hypothesised that occupational sitting time, categorised as less than 2 hours per day, at least 2 hours per day, or not being in paid work, would not have an association with GDM or glucose levels because of its inconsistent association with type 2 diabetes in the general population (van Uffelen et al., 2010). However, in this sample, higher occupational sitting was associated with *lower* GDM incidence and glucose levels, such that those who sat for at least 2 hours per day at work had *lower* likelihood of GDM and lower glucose levels than those who sat for less than 2 hours per day (those not in paid work were not significantly different) (Tables 6.26 6.27, 6.28, pages 167-170). No other studies have examined the effects of occupational sitting time during pregnancy, limiting the amount of literature that can be drawn upon to contextualise these findings. While it is possible that this association was detected as an artefact of the way that occupational sitting time was dichotomised, this pattern (of higher occupational sitting time being associated with decreased likelihood of GDM and lower glucose levels) was confirmed when occupational sitting time was examined as a continuous variable (Figure 6.6, page 168, Figure 6.7, page 169).

The synthesis of these differing associations of various measures of sedentary time/behaviour and gestational diabetes/glucose levels offers several important and timely contributions to the literature concerning the effects of sedentary time on glucose metabolism more generally. First, the differences in associations between each of these aspects of sedentary time/behaviour and GDM – particularly the difference in associations between total sedentary time and television time with GDM – highlight different observed effects of 'sitting time' depending on the aspect of sedentary time that is measured. Given that the majority of the evidence base concerning the health effects of 'sedentary time' is actually based on the measurement of television time (Stamatakis et al., 2018), the distinction between television time and total sitting time needs to be explicitly stated and acknowledged more clearly within the literature[37].

Second, possible explanations for why total sedentary time, television time, and occupational sitting time may have such different effects is an ongoing exchange of speculations that have yet to be rigorously tested and untangled. One suggestion has been that television time takes place at night-time and thus impacts postprandial glucose (Patterson et al., 2018, Ekelund et al., 2016). In this sample, those who watched at least two hours of television per day had higher night-time sedentary time (after 6pm) than those who watched less than 2 hours of television per day; this lends some support to they 'timing' hypothesis, although it is unclear whether night-time sedentary time would be sufficient to 'cause' GDM. The other common suggestion is that television time is particularly prolonged, especially compared to occupational sitting, and may be detrimental for that reason (Patterson et al., 2018, Saidj et al., 2013, van der Ploeg and Hillsdon, 2017, Ekelund et al., 2016). Prolonged sedentary time, both for the entire day and just in the evenings, did not differ depending on television time or occupational sitting time; however, those who had higher television time had fewer breaks in sedentary time per day (across the entire day). While this difference was statistically significant, it was only three breaks per

[37] This seems like an obvious point, but it is surprisingly common for the literature to appraise or identify the effects of television time but describe its appraisal as an examination of the effects of 'sedentary behaviour' without acknowledging that the evidence is based upon television time (see Wilmot et al. (2012) for an example of this).

day, thus the clinical significance of this difference and whether it could account for increased GDM incidence is unclear.

Finally, a recurrent suggestion is that the different effects of television time and occupational sitting time on health outcomes are due to differences in socioeconomic patterning (Stamatakis et al., 2018, van der Ploeg et al., 2015, Stamatakis et al., 2013, Pinto Pereira et al., 2012). In this sample, television time was highest among the lowest income group, while occupational sitting time was highest among the high income group. The effects of television time and occupational sitting time in relation to GDM persisted after controlling both individual-level (household income) and area-level (neighbourhood deprivation) indicators of socioeconomic position. This may suggest that the effects of television time and occupational sitting time are independent of socioeconomic position, although it is acknowledged that income and neighbourhood deprivation do not fully capture factors that differ along socioeconomic gradients. Other suggestions are to do with confounding dietary factors (i.e., that snacking concurrent with television time may have the main effect, (Patterson et al., 2018, Whitaker et al., 2018, Stamatakis et al., 2012a, Stamatakis et al., 2012b, Hu et al., 2003, Dunstan et al., 2010, Saidj et al., 2013). However, dietary factors were not measured in this study and thus their contribution to the pathophysiology of GDM cannot be discussed here.

Thus, taken all together, the evidence presented in this thesis suggests that objectively measured sedentary time during pregnancy had an effect on glucose metabolism (but not the development of gestational diabetes) in this sample. The effects of time spent watching television and sitting at work in relation to incident GDM warrant further investigation.

8.1.2 Sedentary time and other pregnancy outcomes

A minor aim of this thesis was to examine the associations of sedentary time and sedentary behaviours with other pregnancy outcomes, including blood pressure, gestational age at delivery, neonatal birthweight, and neonatal macrosomia. The associations between objectively-measured sedentary time and these outcomes were examined in this study because other studies have tested them, all reporting null associations; however, the other studies had major limitations in their objective measurements of sedentary time. Thus, the rationale was to examine whether a high-

quality measurement of sedentary would detect an association, while also investigating whether time spent in specific sedentary 'behaviours' (e.g., television time) would have associations.

In this sample, no measures of sedentary time (total, prolonged, breaks, compositional) or behaviours (television time, occupational sitting time) had any associations with any of the other pregnancy outcomes. This fits within the null findings of the other studies (Loprinzi et al., 2013, Hayes et al., 2014, Badon et al., 2018, Ruifrok et al., 2014) and suggests that their null findings may not have necessarily been due to limitations in the measurement of sedentary time. It should be noted that these null findings must be interpreted carefully because the power calculation was done based on gestational diabetes, thus associations may exist and may simply require a larger sample to detect.

8.1.3 Patterning of sedentary time and sedentary behaviours during pregnancy

A secondary aim of this thesis was to examine the ways in which sedentary time and sedentary behaviours (television time and occupational sitting time) are patterned by day of the week, by hour of the day, and by sociodemographic factors. In this sample, objectively measured sedentary time was highest on Sundays (Figure 5.2 page 120) and at night-time (on all days; Figure 5.4, page 121), and highest among those with higher household incomes, lower neighbourhood deprivation (although this was not a linear pattern), and younger participants (Table 5.6, page 124). This is useful information for identifying where sedentary time might be the highest within and between individuals, and thus may be helpful for designing any interventions to reduce sitting time.

Given that higher occupational sitting time was associated with higher total sedentary time (Table 5.14, page 134), one strategy for reducing total sedentary time may be targeting sitting time within the workplace, which is a common approach for sedentary interventions (Chu et al., 2016, Shrestha et al., 2018b). However, this strategy may be limited in its effectiveness unless the workplace as a whole is involved and supportive of the intervention, at least in part due to the social perception of sitting at work being associated with productivity and commitment to the job (De Cocker et al., 2015, Niven and Hu, 2018, Mackenzie et al., 2018).

In this sample, television time (≥2 hours per day) was higher among lower-income groups (Table 5.9, page 129). Because most of the evidence base concerning the health effects of sitting has been based upon measures of television time (Stamatakis et al., 2018), the reduction of television time has been a target of intervention (Owen et al., 2011). Since television time is higher among lower socioeconomic groups (as measured by income or education), these individuals may disproportionately be the primary targets of these interventions. However, in this sample as well as others (Clark et al., 2011a) television time did not reflect total sitting time; importantly, while those from the lowest-income group in this sample had the highest television time, they also had the lowest objectively measured sedentary time. This suggests that, while interventions to reduce television time may seem important because of the observed link between higher television time and GDM in this study, further research is needed before any interventions might be designed to understand *why* television time has such a pronounced association with GDM (as well as type 2 diabetes, and other poor health outcomes). If television time is linked to GDM because it happens at night (as was the case in this sample) and if its timing is truly the driver behind impaired glucose metabolism, then reducing television time might be an important strategy to reduce likelihood of incident GDM. However, if television time is simply a proxy for other indicators of social inequalities in health (e.g., lower socioeconomic position) and if it is thus not actually the sitting linked to television time that contributes to GDM risk, strategies to reduce television time (which would disproportionately target lower socioeconomic groups) would not be fruitful.

8.1.4 Social context of sedentary time during pregnancy

The third main aim of this thesis was to explore the social context of sedentary time during pregnancy. Through the semi-structured interviews, a key theme emerged that there was a social expectation for women to sit down and slow down during their pregnancies regardless of how they themselves felt at a given time. The purpose of the interviews was not necessarily to theorise why women might be encouraged to sit or discouraged from being active during their pregnancies, although suggestions were offered in the literature review for why this might be. While this study was not the first to report that pregnant women are often told to sit down and to rest (Evenson et al., 2009, Oakley, 1979, Denison et al., 2015, Flannery et

al., 2018), this study was the first to bring this social expectation to the forefront of analyses.

The finding that there is a social expectation for women to sit down and reduce their physical activity during pregnancy is important. When correlates of physical activity during pregnancy are explored in both qualitative and quantitative studies, 'barriers' to activity are often reported at the level of the individual (e.g., physical symptoms or lack of motivation) (Coll et al., 2016). While 'interpersonal' effects such as 'lack of social support' are often mentioned, the conclusions of such studies still identify the individual as the site in need of intervention. The findings from the interviews in this study highlighted that social expectations and personal capability/desire often conflicted, requiring women to negotiate these differences. This has important implications for the design of any interventions to increase physical activity or reduce sedentary time during pregnancy: if the broader public are not also involved, and if the overall aim of the intervention does not address changing societal attitudes toward activity during pregnancy, interventions are likely to be unsuccessful and, worse yet, may continue to implicate women as the ones 'at fault' for not being 'active enough' during pregnancy.

8.2 Strengths and limitations

The findings and implications of this study must be interpreted in light of the following strengths and limitations of the study.

8.2.1 Strengths

The main strength of this study is its use of an objective measurement of sedentary time using a thigh-worn accelerometer (activPAL) that is designed to differentiate between sitting, standing, and stepping. In addition, a continuous wear protocol was used with the activPAL so that sedentary time across the entire 24-hour period (and not just during select periods of waking hours) could be captured. Furthermore, sleep and non-wear were removed from each activPAL data set using a validated, automated algorithm cross-checked with sleep diaries. This increases the likelihood that sleep was correctly identified and not mistaken for night-time sedentary time (or vice versa).

Semi-structured interviews were used with a specific aim to explore the social contexts of women's experiences during pregnancy. This is a strength because the majority of research aiming to understand factors that affect physical activity during pregnancy are either quantitative and rely on questionnaires which constrain the data, or analyse qualitative data using a theoretical framework that focuses on individual-level factors (e.g., Theory of Planned Behaviour). Having in-depth conversations with women about their everyday lives, and placing women's experiences and interpersonal interactions at the centre of their narratives, provided important and often-ignored contextual information about sedentary time and physical activity.

The participants in this sample, while not ethnically diverse, represented a broad range of socioeconomic backgrounds (particularly low socioeconomic status). This is attributable to the fact that participants were recruited from public hospitals, which provide routine antenatal care to everybody, rather than recruiting from private groups that tend to be utilised by middle class, well-educated women. As research participants tend to be disproportionately middle and upper class, having representation across the socioeconomic spectrum is important.

Finally, this study used a prospective cohort design, in which sedentary time was measured in the second trimester (20 weeks' gestation), prior to the diagnosis of gestational diabetes (usually 24-28 weeks' gestation). This contrasts with most available studies that have used cross-sectional designs to test sedentary time in relation to type 2 diabetes, making causality impossible to assess.

8.2.2 Limitations

The main limitation of this study is that the findings are specific to pregnant women who have a risk factor for gestational diabetes. While it is important to understand the prevalence, correlates, effects, and context of sedentary time in this particular group, the generalisability of these findings to the general pregnant population is unclear.

Another limitation is the possibility of an underpowered sample. This is especially relevant for the null findings in the association between total sedentary time and gestational diabetes. The power calculation (which was based on a meta-analysis in

which the studies predominantly used self-reported television time and sitting time) indicated a minimum sample size of 228; the sample size with complete data in the GDM model was 184. However, it should be noted that the incidence of GDM in this sample (16.1%), which was higher than the expected incidence used in the original power calculation (13.4%), suggests a minimum required sample size of 188 with the original effect size; the effect size in the GDM model was 1.00, suggesting it is unlikely that those four missing participants would have made much difference.

All accelerometry research is limited by the possibility of reactivity. The first day of wear was excluded from the data set to help minimise this effect. While all participants were told not to modify their typical daily patterns during the measurement period and they were not told that the study was focused on the measurement of sedentary time, it is possible that they may have increased their physical activity or decreased their sedentary time during the measurement period.

Sedentary time was only measured once in this study. There is evidence to suggest that sedentary time may change over the course of pregnancy (Hawkins et al., 2017). Longitudinal measures would have been ideal to capture these changes over time; however, this was not feasible due to limited number of activPALs and time available for use in this study.

No dietary factors were measured in this study, which may be a confounding variable that was not controlled. As participants were not compensated for their participation in this study and were already asked to take part in the accelerometry and questionnaires, gathering dietary information seemed excessive. This information would have been useful in the analyses of the association between television time and GDM to determine whether dietary factors may have been a confounding variable.

Finally, the data on television time was dichotomised, not continuous, limiting the level of detail. The structure of the Pregnancy Physical Activity Questionnaire, which provides categorical options to report time-use, did not provide an option to analyse the data as a continuous measure. While it is common within physical activity research to dichotomise or otherwise collapse television time into categorical

variables, continuous measures of television time would have resulted in more in-depth information about its effects.

8.3 Implications of the study findings

The findings of this study have several implications.

The main, practical implication of this study's results is that the modification of sedentary time may provide a strategy for the management of glucose levels during pregnancy. This study showed that total sedentary time was associated with increased glucose levels among those without gestational diabetes, and prolonged sedentary time was associated with higher fasting glucose levels regardless of GDM status. While sedentary time was not linked to the development of gestational diabetes, it may be possible that reducing sedentary time may be a strategy for regulating plasma glucose, which may be most relevant in cases of sub-clinical hyperglycaemia. This study also showed that breaks in sedentary time improved the glucose levels of those diagnosed with GDM, indicating that breaking up sedentary time may be one strategy to reduce glucose levels in this group. Encouraging regular physical activity (particularly MVPA) is a common component of diabetes management (National Institute for Health and Care Excellence, 2015). The findings presented here offer what may be a more accessible alternative by focusing on the reduction and regular interruption of sedentary time rather than solely focusing on increasing higher-intensity physical activity.

Other implications from this study concern the designs of possible interventions. An examination of the patterning of objectively measured sedentary time indicated that sedentary time was highest on Sundays, at night-time, among younger women, among those living in less-deprived neighbourhoods, and among those with higher household incomes. These findings suggest where the highest sedentary time may be located and may thus be good starting places for any interventions to decrease sedentary time during pregnancy. These implications, however, must be interpreted alongside the main implication from the qualitative data. The interview data presented in Chapter 7 highlighted that there is a strong, social expectation for women to sit down and reduce their physical activity during their pregnancies, and this expectation is not necessarily linked to how women themselves are feeling on a given day. This has key implications for the delivery of any interventions to reduce

sedentary time (or increase physical activity) during pregnancy. One possible strategy would be to direct public health messages concerning the benefits of physical activity during pregnancy to the broader public, rather than just pregnant women and their immediate circle, to normalise physical activity during pregnancy (although, notably, that runs the risk of shifting the expectations for what it means to be a 'good mother' and may add a moral implication for physical activity during pregnancy in the opposite direction).

The results of this study also have important implications for research on sedentary time/behaviour more generally. The results from Chapter 6 demonstrated that different aspects of sedentary time and sedentary behaviour (television time, occupational sitting time) have different associations with health outcomes, especially in relation to GDM. This has key implications for the field of sedentary research and the interpretation of the results of studies that have used various measures of sedentary time. Most of the evidence concerning the effects of 'sitting' is based on television time, which may mean that the perceived detrimental impact of sitting time may be exaggerated (Stamatakis et al., 2018). This calls the 'true' magnitude of the effects of total objectively measured sedentary time into question, and mandates that researchers be extremely careful going forward to explicitly separate television time and total sedentary time in literature reviews, terminology, and implications of study findings.

8.4 Directions for future research

The findings of this study have identified several useful avenues for future research.

At minimum, the findings of this study require replication. More specifically, replicating this study's protocol with a larger sample would be useful to see if the same pattern persists. It would be useful to replicate the study among women without a risk factor for gestational diabetes to understand whether the findings of this study are generalisable to the broader pregnant population.

To continue to isolate the 'true' effects of sitting time, future work should continue to use the activPAL to capture sitting time over the 24-hour cycle. This, in combination with the continued use of compositional models, will help disentangle the relative

contributions of sedentary time and physical activity, as well as the interaction between them, in relation to health outcomes.

Further work is needed to untangle why total sedentary time, television time, and occupational sitting time have such different effects, especially in relation to incident gestational diabetes. Specifically, it would be useful for future work to examine whether the differences in effects are attributable to differences in the factors related to actual sitting (e.g., prolonged or interrupted sitting, the timing of the sitting, associated levels of muscular activation), confounding dietary factors (e.g., snacking), or confounding socioeconomic factors. Each of these possibilities need to be explored and carefully statistically modelled to understand their relative contributions.

Ethnographic methods would add depth and further contextual details to the finding that there is a social expectation for women to slow down during their pregnancies, providing further understanding of women's experiences during pregnancy and how these experiences may change as their pregnancies progress.

8.5 Concluding remarks

This PhD project began with the hope of providing an answer to what was (at the time) thought to be a straightforward question: *does sedentary time during pregnancy predict gestational diabetes risk?* The evidence presented in this thesis suggests that sedentary time does indeed influence glucose metabolism during pregnancy, but different aspects of sedentary time (total sedentary time, television time, occupational sitting time) may have different effects. The process of writing this thesis has raised additional and unexpected questions, particularly: *why do total sedentary time, television time, and occupational sitting time have such different associations with gestational diabetes?* Coincidentally, this thesis is raising this question at the same time as several other research groups who are also highlighting that different types of sitting have different associations with health outcomes (Stamatakis et al., 2018, Whitaker et al., 2018, Patterson et al., 2018). I am hopeful that the future efforts of sedentary research will prioritise clarifying these differences through careful constructions of study designs and meticulous communication in the literature to clarify the type of sedentary time/behaviour on which evidence is based. Doing so is

imperative to further our understandings of the impact of sedentary time on health outcomes.

Appendices

Appendix 1: Validation of the waist- and wrist-worn Actigraph for the measurement of sedentary time in laboratory and free-living settings

Table A1. Criterion validity, sensitivity, and specificity of the Actigraph in waist- and wrist-worn configurations compared to direct observation (laboratory-based) or the activPAL (free-living)

Study	Outcome measure	Posture	Waist	Wrist
Laboratory (criterion measure is direct observation)				
Edwardson et al. (2016)	Mean % (95%CI) coded correctly	Lying	72 (65.6-78.2)	N/A
		Sitting	58 (52.5-63.7)	N/A
		Upright	74 (69.3-79.3)	N/A
Hildebrand et al. (2017)	Sensitivity (%)	Sitting	96	98
	Specificity (%)		78	74
An et al. (2017)	Mean absolute % error	Lying down	26.4	45.9
		Sitting	52.1	52.7
		Standing	45.8	91.2
Free living (criterion measure is activPAL)				
Koster et al. (2016)	Sensitivity (%)	Sitting	93.6	81.5
	Specificity (%)		58.1	76.6
Hildebrand et al. (2017)	Sensitivity (%)	Sitting	97	87
	Specificity (%)		26	49

Appendix 2: Modifiable STATA code for removing invalid activPAL data and sleep time

```
*************************************************************************
* This file codes bouts as 'sleep' time (e.g. sleep, prolonged removals
etc) & codes invalid days *
* It uses ActivPal event files
* Two output files are generated: "sleep_algorithm" contains bout level
data;                     *
*  "sleep times_algorithm" contains times for each episode of
sleep/prolonged removal. Both files *
*  are saved as .dta and .csv files
* Author: Danielle Bodicoat (07/10/2015)
* With thanks to Charlotte Edwardson, Kishan Bakrania, and Lis Winkler for
valuable input         *
* Disclaimer: This code is provided with the hope that it will be helpful,
but without any        *
* warranty or implied warranty of fitness for a particular purpose
                    *
*************************************************************************
capture clear all
set more off
*********************************************************
** THIS SECTION WILL NEED EDITING FOR EACH SPECIFIC USE **
** USERS DO NOT NEED TO EDIT ANYTHING ELSE IN THIS FILE **
*********************************************************
** EDIT: set directory where event files are stored **
** ActivPal event files should be stored as separate csv files in the same
folder
** STATA expects csv files to have a .csv extension in lower case (Code may
not work if other extensions are used)
** THIS CODE WILL OVERWRITE THE EVENT FILES IN THIS FOLDER SO MAKE SURE A
COPY IS MADE
** To start with the folder should contain nothing but the ActivPal event
files so if you re-run this code you will need to start by putting the
original ActivPal event files into a new folder
cd "E:\Day 1\Training folder\Event files\Files for sleep algorithm"

** EDIT: set parameters for defining valid days - Change last value in each
row (i.e. the numerical value)**
* Maximum percentage in one activity for a valid day (e.g. 95%)
local prop=95
```

```
* Minimum no of steps for a valid day (e.g. 500)
local min_steps=500
* Minimum hours of data for a valid day in seconds (e.g. 36000 seconds = 10
hours)
local min_hrs=36000

** EDIT: tell STATA the location of the unique subject ID in the .csv file
name
* Start is the location of the first digit of the subject ID in the
filename
* Number is the number of digits in the subject ID
* E.g. for csv files named "NNNLL-AP1133030 16May13 10-00am for 7d 13h 0m
Events.csv" where the subject ID is NNNLL then start = 1 and number = 5
* E.g. for csv files named "EVENTS_PLUS_SR_NNNN.csv" where the subject ID
is NNNN then start = 16 and number = 4
local start=1
local number=6

**EDIT: tell STATA the name of key variables (change last name in each row)
**NOTE: STATA only allows the digits 0-9 and the alphabet letters in
variable names so all other characters (nicluding spaces) will be removed
*Variable where activity code is stored (0=sedentary, 1=standing,
2=stepping)
*E.g. if your activity code variable is called activitycode then change the
following line to local activity="activitycode"
local activity="activitycode"
*Variable where length of bout is stored in seconds
local length="intervals"
*Variable where the date and time when the bout started is stored
*E.g. if your date & time field is called time then change the following
line to local datetime="time"
local datetime="time"

** EDIT: set parameters for defining sleep/prolonged removals - Change last
value in each row (i.e. the numerical value)**
* Minimum bout length for a second long sedentary/standing bout in initial
bout identification in seconds (e.g. 18000 seconds = 5 hours)
local min_second=18000
* Check window length in minutes (e.g. 15 minutes)
local check=15
```

```
* Minimum length of long sedentary bout in seconds (e.g. 7200 seconds = 2
hours)
local min_long=7200
* Maximum number of steps (e.g. 20)
local max_steps=20
* Minimum length of short sedentary bout in seconds (e.g. 1800 seconds = 30
mins)
local min_short=1
```

Appendix 3: Pregnancy Physical Activity Questionnaire (PPAQ)

Study ID:

Pregnancy Physical Activity Questionnaire: Second Trimester
Title of Study: Mobility and Maternity: the MaM study
Lead Researcher: Janelle Wagnild, Durham University, j.m.wagnild@dur.ac.uk

It is very important that you answer these questions as honestly as you can. There are no right or wrong answers. We just want to know about the things you were doing in each trimester.

Participant name: _____

At home…

During your SECOND TRIMESTER, when you were NOT at work, how much time did you usually spend:

1. **Preparing meals (cook, set table, wash dishes)**
   - o None
   - o Less than ½ hour per day
   - o ½ to almost 1 hour per day
   - o 1 to almost 2 hours per day
   - o 2 to almost 3 hours per day
   - o 3 or more hours per day
2. **Dressing, bathing, feeding children while you are sitting**
   - o None
   - o Less than ½ hour per day
   - o ½ to almost 1 hour per day
   - o 1 to almost 2 hours per day
   - o 2 to almost 3 hours per day
   - o 3 or more hours per day
3. **Dressing, bathing, feeding children while you are standing**
   - o None
   - o Less than ½ hour per day
   - o ½ to almost 1 hour per day
   - o 1 to almost 2 hours per day
   - o 2 to almost 3 hours per day
   - o 3 or more hours per day
4. **Playing with children while you are sitting or standing**
   - o None
   - o Less than ½ hour per day
   - o ½ to almost 1 hour per day
   - o 1 to almost 2 hours per day
   - o 2 to almost 3 hours per day
   - o 3 or more hours per day
5. **Playing with children while you are walking or running**
   - o None
   - o Less than ½ hour per day
   - o ½ to almost 1 hour per day
   - o 1 to almost 2 hours per day
   - o 2 to almost 3 hours per day
   - o 3 or more hours per day
6. **Carrying children**
   - o None
   - o Less than ½ hour per day
   - o ½ to almost 1 hour per day
   - o 1 to almost 2 hours per day
   - o 2 to almost 3 hours per day
   - o 3 or more hours per day
7. **Taking care of an older adult**
   - o None
   - o Less than ½ hour per day
   - o ½ to almost 1 hour per day
   - o 1 to almost 2 hours per day
   - o 2 to almost 3 hours per day
   - o 3 or more hours per day
8. **Sitting and using a computer, tablet, or writing while NOT at work**
   - o None
   - o Less than ½ hour per day
   - o ½ to almost 1 hour per day
   - o 1 to almost 2 hours per day
   - o 2 to almost 3 hours per day
   - o 3 or more hours per day
9. **Watching TV or films**
   - o None
   - o Less than ½ hour per day
   - o ½ to almost 2 hours per day
   - o 2 to almost 4 hours per day
   - o 4 to almost 6 hours per day
   - o 6 or more hours per day

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Pregnancy Physical Activity Questionnaire: Second Trimester

During your SECOND TRIMESTER, when you were NOT at work, how much time did you usually spend:

10. **Sitting and reading, talking, or on the phone while NOT at work**
    - o None
    - o Less than ½ hour per day
    - o ½ to almost 2 hours per day
    - o 2 to almost 4 hours per day
    - o 4 to almost 6 hours per day
    - o 6 or more hours per day
11. **Playing with pets**
    - o None
    - o Less than ½ hour per day
    - o ½ to almost 1 hour per day
    - o 1 to almost 2 hours per day
    - o 2 to almost 3 hours per day
    - o 3 or more hours per day
12. **Light cleaning (make beds, laundry, iron, put things away)**
    - o None
    - o Less than ½ hour per day
    - o ½ to almost 1 hour per day
    - o 1 to almost 2 hours per day
    - o 2 to almost 3 hours per day
    - o 3 or more hours per day
13. **Shopping (for food, clothes, or other items)**
    - o None
    - o Less than ½ hour per day
    - o ½ to almost 1 hour per day
    - o 1 to almost 2 hours per day
    - o 2 to almost 3 hours per day
    - o 3 or more hours per day
14. **Heavier cleaning (vacuum, mop, sweep, wash windows)**
    - o None
    - o Less than ½ hour per week
    - o ½ to almost 1 hour per week
    - o 1 to almost 2 hours per week
    - o 2 to almost 3 hours per week
    - o 3 or more hours per week
15. **Mowing lawn while on a riding mower**
    - o None
    - o Less than ½ hour per week
    - o ½ to almost 1 hour per week
    - o 1 to almost 2 hours per week
    - o 2 to almost 3 hours per week
    - o 3 or more hours per week
16. **Mowing lawn using a walking mower, raking, gardening**
    - o None
    - o Less than ½ hour per week
    - o ½ to almost 1 hour per week
    - o 1 to almost 2 hours per week
    - o 2 to almost 3 hours per week
    - o 3 or more hours per week

Going places… During your SECOND TRIMESTER, how much time did you usually spend:

17. **Walking slowly to go places (such as to the bus, work, visiting) NOT for fun or exercise**
    - o None
    - o Less than ½ hour per day
    - o ½ to almost 1 hour per day
    - o 1 to almost 2 hours per day
    - o 2 to almost 3 hours per day
    - o 3 or more hours per day
18. **Walking quickly to go places (such as to the bus, work, or school) NOT for fun or exercise**
    - o None
    - o Less than ½ hour per day
    - o ½ to almost 1 hour per day
    - o 1 to almost 2 hours per day
    - o 2 to almost 3 hours per day
    - o 3 or more hours per day
19. **Driving or riding in a car or bus**
    - o None
    - o Less than ½ hour per day
    - o ½ to almost 1 hour per day
    - o 1 to almost 2 hours per day
    - o 2 to almost 3 hours per day
    - o 3 or more hours per day

Version 1.3 | 20 July 2016

Pregnancy Physical Activity Questionnaire: Second Trimester

For fun or exercise…
During your SECOND TRIMESTER, how much time did you usually spend…

20. Walking slowly for fun or exercise
- o None
- o Less than ½ hour per week
- o ½ to almost 1 hour per week
- o 1 to almost 2 hours per week
- o 2 to almost 3 hours per week
- o 3 or more hours per week

21. Walking more quickly for fun or exercise
- o None
- o Less than ½ hour per week
- o ½ to almost 1 hour per week
- o 1 to almost 2 hours per week
- o 2 to almost 3 hours per week
- o 3 or more hours per week

22. Walking quickly up hills for fun or exercise
- o None
- o Less than ½ hour per week
- o ½ to almost 1 hour per week
- o 1 to almost 2 hours per week
- o 2 to almost 3 hours per week
- o 3 or more hours per week

23. Jogging
- o None
- o Less than ½ hour per week
- o ½ to almost 1 hour per week
- o 1 to almost 2 hours per week
- o 2 to almost 3 hours per week
- o 3 or more hours per week

24. Antenatal exercise class
- o None
- o Less than ½ hour per week
- o ½ to almost 1 hour per week
- o 1 to almost 2 hours per week
- o 2 to almost 3 hours per week
- o 3 or more hours per week

25. Swimming
- o None
- o Less than ½ hour per week
- o ½ to almost 1 hour per week
- o 1 to almost 2 hours per week
- o 2 to almost 3 hours per week
- o 3 or more hours per week

26. Dancing
- o None
- o Less than ½ hour per week
- o ½ to almost 1 hour per week
- o 1 to almost 2 hours per week
- o 2 to almost 3 hours per week
- o 3 or more hours per week

27. Other things for fun or exercise? Please tell us what they are

_____
_____

- o None
- o Less than ½ hour per week
- o ½ to almost 1 hour per week
- o 1 to almost 2 hours per week
- o 2 to almost 3 hours per week
- o 3 or more hours per week

28. Other things for fun or exercise? Please tell us what they are

_____
_____

- o None
- o Less than ½ hour per week
- o ½ to almost 1 hour per week
- o 1 to almost 2 hours per week
- o 2 to almost 3 hours per week
- o 3 or more hours per week

Pregnancy Physical Activity Questionnaire: Second Trimester

Please fill out the next section if you worked for wages, as a volunteer, or if you were a student during your SECOND TRIMESTER. If you were a homemaker, out of work, or unable to work, you do not need to complete this last section.

At work…

During your SECOND TRIMESTER, how much time did you usually spend…

29. **Sitting at work or at college**
    - None
    - Less than ½ hour per day
    - ½ to almost 2 hours per day
    - 2 to almost 4 hours per day
    - 4 to almost 6 hours per day
    - 6 or more hours per day
30. **Standing or slowly walking at work while carrying things (heavier than 2 4-pint milk containers)**
    - None
    - Less than ½ hour per day
    - ½ to almost 2 hours per day
    - 2 to almost 4 hours per day
    - 4 to almost 6 hours per day
    - 6 or more hours per day
31. **Walking quickly at work while carrying things (heavier than 2 4-pint milk containers)**
    - None
    - Less than ½ hour per day
    - ½ to almost 2 hours per day
    - 2 to almost 4 hours per day
    - 4 to almost 6 hours per day
    - 6 or more hours per day
32. **Standing or slowly walking at work while NOT carrying things**
    - None
    - Less than ½ hour per day
    - ½ to almost 2 hours per day
    - 2 to almost 4 hours per day
    - 4 to almost 6 hours per day
    - 6 or more hours per day
33. **Walking quickly at work NOT carrying anything**
    - None
    - Less than ½ hour per day
    - ½ to almost 2 hours per day
    - 2 to almost 4 hours per day
    - 4 to almost 6 hours per day
    - 6 or more hours per day

This is the end of the questionnaire.
Please return this to a member of the research team.
Thank you!

Version 1.3 | 20 July 2016

Appendix 4: Participant Information Sheet (PIS)

Participant information sheet

City Hospitals Sunderland NHS Foundation Trust | County Durham and Darlington NHS Foundation Trust | The Newcastle Upon Tyne Hospitals NHS Foundation Trust | Durham University

INFORMATION FOR VOLUNTEERS

Title of the Study: Mobility and Maternity: the MaM study

PhD project by: Janelle Wagnild under the supervision of Prof Helen Ball & Dr Tessa Pollard
Department of Anthropology, Durham University, Stockton Road, Durham, DH1 3LE
j.m.wagnild@durham.ac.uk | mobile: 07432 810144
[Local PI and Research Team contacted to be added here]

You are invited to take part in a study looking at mobility patterns during pregnancy.

What is the study about? The purpose of this project is to find out whether mobility patterns (i.e., time spent moving or resting) have any impact on the likelihood of developing gestational diabetes or other common pregnancy complications.

Who can participate? Women with a risk factor for gestational diabetes who are less than 15 weeks pregnant, between the ages of 18 and 40, expecting one baby, who do not have type 1 or type 2 diabetes and who are not taking medication for chronic hypertension are invited to take part in this study.

What happens if I choose to participate? If you agree to participate 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 information about yourself. You will also be asked to complete two questionnaires that ask about activities you do in a typical day.

At around week 18 of your pregnancy, the research team will contact you to ask if you are still willing to participate in the project. If you are, you will be fit with a small device called an activPAL at your 20-week scan at the hospital that you will be asked to wear for one week. The activPAL detects whether you are sitting or lying down, standing, or moving (e.g. walking, running, cycling) and records how much time you spend doing each. It sticks to your skin and is worn underneath clothing, so it should not interfere with your everyday life in any way. After the week is over, a member of the research team will come collect the device from you at home if possible; if not, other arrangements will be made to collect it.

You will be asked to complete two more questionnaires about typical daily activities two more times: once in your second trimester (at your 20-week scan) and again in your third trimester (between weeks 31-36 either at your community midwife appointment or via the post or email based on your individual preference). It takes 10 to 15 minutes to complete each questionnaire.

Finally, you will be invited to take part in an optional one-to-one interview that will last for about one hour in order to get an idea of what your experience of your pregnancy has been like. This will occur in your home or another mutually convenient and comfortable location between weeks 30 and 32 of your pregnancy. What is discussed in the interview will be kept confidential UNLESS something said in the conversation leads the researcher to believe that you or your baby are in danger; the researcher will notify your midwife or GP if this happens. If you would rather not be interviewed, you are still welcome to participate in the rest of the project.

Version 1.3 | 20 July 2016
When completed: 1 for participant; 1 for site file; 1 for medical records; 1 (original) for researcher

You will also be asked to give the research team permission to access your medical records specific to your pregnancy. This is so that they can find out the results of your gestational diabetes screening, what your blood pressure levels were like during your pregnancy, and find out if any other issues arose with your pregnancy or delivery (e.g. pre-eclampsia, early or late delivery, high or low birth weight). This information will be kept completely confidential.

Are there any benefits to me if I choose to participate? There are no direct benefits to you if you choose to participate. However, your participation will go towards helping us understand risk factors for gestational diabetes and other pregnancy complications which benefits everyone.

Are there any risks to me if I choose to participate? There are no foreseen risks to you or your baby if you decide to participate. This study simply measures your typical mobility patterns; you will not be asked to do anything differently than you normally would.

What if something goes wrong? If you have a health emergency, please contact emergency health services (999) immediately. If you have questions or concerns about the study, please contact the lead researcher (email: j.m.wagnild@dur.ac.uk | telephone: 07432 810144). You can also contact the Patient Advice and Liaison Service (PALS) based in your local hospital.

What happens if I change my mind about participating? You do not have to take part in this study, though we hope you will choose to help us. If you change your mind and decide you do not wish to continue at any time, just tell us you want to withdraw. You do not need to give a reason. You may request to have any of your data that had been collected up until the point of withdrawal destroyed.

Confidentiality: All information we collect will be safely stored and not shared with anyone else. A code will be used so that your name will not appear on any of the data sheets. There will be no way of identifying you. Any reports or publications from this study will include summarised information or anonymous quotations so that you cannot be identified. Approval has been obtained from the NHS Research Ethics Committee (reference: 16/SC/0355) and the Durham University Ethics Committee, and this project is covered by Durham University insurance. Your GP will be made aware that you are participating in the study, but information that you share with the research team that is not a part of your medical records will not be shared with your GP unless the research staff have reason to believe that the wellbeing of you and/or your unborn baby may be at risk.

What happens to the results of this study? The results of this study will be analysed and published in Janelle's PhD thesis and other scientific reports. Your identity as a participant will remain confidential. You may ask for a copy of the results.

Who is organising this study? This study is the PhD project of Janelle Wagnild in the Department of Anthropology and Durham University. She is supervised by Prof Helen Ball and Dr Tessa Pollard.

Disclaimer: Durham University has in force a Policy providing legal liability cover and the activities here are included within that coverage.

Thank you for reading this information and considering taking part in the study. If you have any questions, please speak to the research team.

Appendix 5: Study consent form

Participant consent form
Study ID Number:

City Hospitals Sunderland NHS Foundation Trust | County Durham and Darlington NHS Foundation Trust | The Newcastle Upon Tyne Hospitals NHS Foundation Trust | Durham University

MaM The Mobility & Maternity Study

CONSENT FORM

Title of study: Mobility and Maternity: the MaM study
Lead researcher: Janelle Wagnild | j.m.wagnild@dur.ac.uk | 07432 810144

Please initial box

1. I confirm that I have read the information sheet dated _____ version ____ for this study and had the chance to consider the information. ☐
2. I have had the chance to ask questions and have these answered by the research team. ☐
3. I understand taking part in this study is voluntary and that I am free to withdraw at any time without giving any reason, and without my medical care or legal rights being affected. ☐
4. I give permission to the research team to contact my GP to access my medical records. ☐
5. I give permission to the research team to access my medical records regarding my health during my pregnancy. ☐
6. I am willing to participate in this study. ☐

_____	_____	
Participant name	Participant signature	Date
_____	_____	
Name of person taking consent	Researcher signature	Date

Version 1.2 | 23 June 2016
When completed: 1 for participant; 1 for site file; 1 for medical records; 1 (original) for researcher

Appendix 6: Study enrolment form

Participant enrolment form
Study ID:

STUDY ENROLMENT FORM for the Mobility and Maternity: the MaM study
Lead researcher: Janelle Wagnild | j.m.wagnild@dur.ac.uk | 07432 810144

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?

- o Post
- o Phone call
- o Email
- o Text message
- o Other: _____

Can we call either of the phone numbers you gave us? Yes No

ENROLMENT INFORMATION

When is your due date? _____

Are you between the ages of 18 and 40?	Yes	No	
Are you expecting more than one baby (e.g., twins)?	Yes	No	
Have you been diagnosed with Type 1 or Type 2 diabetes?	Yes	No	
Are you currently taking any medication to manage blood pressure?	Yes	No	
Would you be interested in being interviewed (this is completely optional)?	Yes	No	Maybe
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.

PLEASE SEE OTHER SIDE FOR MORE QUESTIONS

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Version 1.3 | 20 July 2016

BACKGROUND INFORMATION

There are many factors that make women more or less likely to develop gestational diabetes and other pregnancy complications. We need to know if any of these factors apply to you. Please answer the questions below by circling the answer or filling in the blank.

1. **What is your date of birth?** _____

2. **What best describes your ethnic background? (e.g, White British, British Pakistani, etc.)**
   _____

3. **In what country were you born?** (circle one)
   United Kingdom / Ireland / Other: _____

4. **What best describes your highest educational qualification?** (circle one)
   None / GCSEs or equivalent / A levels / University / Postgraduate degree / Other

5. **What is your marital status?** (circle one)
   Married / Living with partner / With partner, living apart / Single, no partner

6. **Into which income category does your household fit?** (circle one)
   Less than £20,000 / Up to £40,000 / Up to £60,000 / Up to £100,000 / Above £100,000

7. **Prior to this pregnancy, how many full-term pregnancies have you experienced?** (circle one)
   0 / 1 / 2 / 3 / 4 or more

8. **How many children currently live at home with you?** (circle one)
   0 / 1 / 2 / 3 / 4 or more

9. **Are you currently employed?** (circle all that apply)
   Full-time / Part-time / Student / Not employed

10. **If you are employed, what is your job?** _____

11. **In the two months before you knew you were pregnant, what was your BMI?**
    Less than 18.5 / 18.5 to 24.9 / 25 to 29.9 / 30 to 39.9 / More than 40
    If you do not know your pre-pregnancy BMI, please provide your pre-pregnancy height and weight here:
    Height: _____ *Weight:* _____

12. **Have you smoked at all during this pregnancy?** (circle one)
    Yes, and I still do / Yes, but I have stopped / Only sometimes / Not at all

13. **Have you ever been diagnosed with gestational diabetes before?** (circle one)
    Yes / No / Not sure

14. **Has any member of your immediate family (parent or sibling) been diagnosed with Type 1 or Type 2 diabetes?** (circle one)
    Yes / No / Not sure

Thank you for taking the time to fill out this form. Please return this form to the research team

Appendix 7: activPAL wear instructions and sleep/non-wear diary

Participant Wear Instructions for activPAL
Study ID:

ACTIVPAL WEAR INSTRUCTIONS
Title of the study: Mobility and Maternity: the MaM study
Researcher: Janelle Wagnild | j.m.wagnild@dur.ac.uk | 07432 810144

What is this device?
This device is called an activPAL. It is an accelerometer that measures mobility patterns based on the way that your thigh moves throughout the day. It records if you are sitting, lying down, standing, or moving; it cannot tell what specific activities you are doing.

How long do I need to wear it?
For best results, wear the device for **7 full days.** You must remove the device if you go swimming or take a bath since **the device cannot be fully submerged in water.** You can wear it in the shower, while you sleep, and while you do any other activities. Please wear it **24 hours per day,** taking it off only if necessary, so that we have enough information.

What should I do while wearing it?
Please do things as normally as you can! The goal is to measure what is typical for you. Do your best to avoid changing your behaviour while the device is on.

In order to help the researchers interpret your data, **please complete the diary you have been given**. The diary asks you to record when you go to bed at night and get out of bed in the morning and when you take the device off.

Do I need to switch the device on or off?
No. The device has been programmed by a computer to begin recording at _____ (time) on _____ (date). It will stop recording at _____ (time) on _____ (date).

PLEASE SEE REVERSE FOR MORE IMPORTANT INFORMATION

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When do I take it off?

The activPAL is water-resistant, but it cannot be placed completely underwater. Please take it off if you go swimming or take a bath and put it back on as soon as you can using the extra adhesive you have been given. When you remove the device, the old adhesive will stick tightly to the activPAL; simply wrap the old adhesive around the device, and use a new piece of adhesive to reattach the device (see instructions below). **Do not attempt to peel the old adhesive off the activPAL as this may rip the waterproof covering.**

How do I put it back on if I have taken it off?

Step 1: While sitting down, place the activPAL on your thigh where you are going to attach it, midway between your hip and knee on the front of your thigh

Step 2: Make sure you can see the words 'top' and 'bottom', and that they are facing the right direction ('top' should point toward your hip)

Step 3: Remove the white backing of the adhesive

Step 4: Place the sticky side down to cover the device and skin around it

Step 5: Peel away the top (clear) layer of the adhesive

Step 6: Smooth out any wrinkles or gaps, making sure the edges are firmly sealed

PLEASE NOTE

Some people find that their skin gets irritated after a few days of wearing the activPAL. This is usually a mild, itchy rash. If this happens to you, please take the activPAL off and either move it to your left thigh or stop wearing it completely. This irritation can be prevented if you move the device to the opposite leg every couple of days and reattach it as instructed.

What happens when the 7 days are over?

The device will stop recording at _____ (time) on _____ (date). You may take the device off at this time.

A member of the research team will make arrangements with you to get the device back so that it can be used for another participant as soon as possible. In most cases, a researcher will arrange with you to come to your home to collect the device, but arrangements may also be made to post the device or bring it to the hospital based on what works best for you.

What if I have questions?

Please contact Janelle Wagnild (email: j.m.wagnild@dur.ac.uk; mobile: 07432 810144) with any questions you may have about the attachment, use, or purpose of the device.

The research team will check in with you during the seven days to see how you are getting on with the device. They will also contact you to discuss what arrangements work best for you to return the device to the research team.

Study ID:

activPAL Wear Diary

Title of the study: Mobility and Maternity: the MaM study

Lead researcher: Janelle Wagnild | j.m.wagnild@dur.ac.uk 07432 810144

In order for us to understand your accelerometer data, we will need you to record some information during the seven days that you wear the accelerometer. We need to know when you put the device on for the first time, any times that you take the device off, and when you go to bed at night and wake up in the morning or take any naps. Please fill out this information as accurately as you can in the tables on both sides of this page and **return this sheet to the research team along with the accelerometer.**

Your device is set to start recording at: _____

Your device will stop recording at: _____

Please record when you first put the device on:

Date: _____ Time: _____

Non-wear time

We need you to record any time you take the device off. Please record this in the table below. **'Time device was removed** is the time of day that the device was taken off and **'time device was put back on** is the time that you reattach the device to your thigh. For **'Reason,'** please tell us why you took the device off, for example to take a bath or because of skin irritation. We need this information so we have some idea of what your activity level was like when you were not wearing the device.

Date	Time device was removed	Time device was put back on	Reason

Please see the other side of this sheet for more important information

Naps and nighttime sleep

Please record your sleep in the table below. **'Start time'** is the time that you get into bed or lie down, either to sleep at night or to take a nap. **'End time'** is the time that you get out of bed in the morning or the end of your nap. You do not need to tell us whether you were awake or asleep (for example, if you went to bed at 9:00 but fell asleep at 10:00, record 9:00). You also do not need to account for getting up in the middle of the night to use the toilet, etc.

Date	Start time	End time

Please return this diary to the research team along with the activPAL accelerometer

Appendix 8: Outcome variable case report form

Medical Records Checklist

Study ID:	

OUTCOME VARIABLES CHECKLIST

Title of Study: The mobility of maternity: the MoM study

Participant ID:	Records retrieved by (initials):
Date of record retrieval:	

Instructions: Please complete both sides of this form. If information is not included in medical records, please check 'data unavailable' box. **Please do not leave anything blank.** Spaces for notes and details have been provided to record additional details that may vary on a case-by-case basis; these may be left empty if there are no additional details to report.

Gestational diabetes details

Was participant screened for GDM?	☐ Yes ☐ No ☐ Data unavailable	IF YES, for what reason was the participant screened? ☐ High BMI ☐ Previous macrosomic (>4.0kg) baby ☐ Previous GDM diagnosis ☐ Family history of diabetes ☐ South Asian origin ☐ Polycystic ovary syndrome ☐ Other: _____
IF YES, what was the OGGT result (glucose level)?	_____ mg/dL ☐ Data unavailable	
IF YES, was participant diagnosed with GDM?	☐ Yes ☐ No ☐ Data unavailable	
IF YES, what was the date of the diagnosis?	_____ ☐ Data unavailable	

Blood pressure details

Appointment	BP measures	
Booking	_____/_____ mmHg	☐ Data unavailable
16	_____/_____ mmHg	☐ Data unavailable
24	_____/_____ mmHg	☐ Data unavailable
28	_____/_____ mmHg	☐ Data unavailable
32	_____/_____ mmHg	☐ Data unavailable
34	_____/_____ mmHg	☐ Data unavailable
36	_____/_____ mmHg	☐ Data unavailable
38	_____/_____ mmHg	☐ Data unavailable
39	_____/_____ mmHg	☐ Data unavailable
40	_____/_____ mmHg	☐ Data unavailable

Diagnosed with gestational hypertension?	☐ Yes ☐ No ☐ Data unavailable	Notes:
Diagnosed with pre-eclampsia?	☐ Yes ☐ No ☐ Data unavailable	

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Gestational weight gain		
BMI at booking appointment: _____	Comments in records about excessive gestational weight gain?	☐ Yes ☐ No
If comments about weight gain, details:		

Delivery details		
Date of delivery: _____		
Delivery occurred via: (circle one)	Vaginal / Emergency c-section / Elective c-section / Other / Data unavailable	
Was the birth pre-term (<37 weeks)?	☐ Yes ☐ No ☐ Data unavailable	Notes about delivery:
Was the birth post-term (>42 weeks)?	☐ Yes ☐ No ☐ Data unavailable	
Was the birth induced?	☐ Yes ☐ No ☐ Data unavailable	

Baby details			
Weight of baby at birth	_____ grams	Sex of baby	☐ Male ☐ Female
Concerns about fetal health in record?	☐ Yes ☐ No ☐ Data unavailable		
If yes, details:			

General notes:

Appendix 9: Interview consent form

Participant interview consent form
Study ID Number:

INTERVIEW CONSENT FORM
Title of study: Mobility and Maternity: the MaM study
Lead Researcher: Janelle Wagnild | j.m.wagnild@dur.ac.uk | 07432 810144

	Please initial box
1. I understand that taking part in this interview is voluntary and that I am free to stop the interview at any time for any reason.	☐
2. I give permission for the interview to be audio recorded so that the conversation can be transcribed later.	☐
3. I give permission for quotations from the interview to be used anonymously in publications that might come from this project.	☐
4. I understand that what we discuss in the interview will remain confidential UNLESS I share information that may indicate there is a risk posed to myself or others. If this should occur, I understand that the researcher will be bound to inform members of the multi-disciplinary care team.	☐
5. I am willing to participate in this interview.	☐

Participant name _____ Participant signature _____ Date _____

Name of person taking consent _____ Researcher signature _____ Date _____

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Appendix 10: NHS Research ethics committee (REC) approval letter

NHS
Health Research Authority

South Central - Oxford B Research Ethics Committee

Whitefriars
Level 3, Block B
Lewin's Mead
Bristol
BS1 2NT

Tel: 0207 104 8043

19 September 2016

Dr Russell Hill
Social Science & Health Faculty Office
Arthur Holmes Building, Lower Mountjoy, Durham University
South Road, Durham
DH1 3LE

Dear Dr Hill

Study title:	**The mobility and maternity (MaM) study: testing the relationship between sedentary behaviour and gestational diabetes risk**
REC reference:	**16/SC/0355**
Amendment number:	**1**
Amendment date:	**11 August 2016**
IRAS project ID:	**196508**

The above amendment was reviewed at the meeting of the Sub-Committee held on 26 August 2016 in correspondence.

Ethical opinion: Favourable

The members of the Committee taking part in the review gave a favourable ethical opinion of the amendment on the basis described in the notice of amendment form and supporting documentation.

Summary of Discussion

The Committee noticed that you are looking to add posters in clinics where booking visits occur for women to pick up before their booking visits, however queried now that the study is only working with a subset of pregnant women, how will women be able to identify themselves as at risk of gestational diabetes prior to the booking visit.

You clarified that the posters in the clinics are intended to be a secondary form of recruitment and that you expect that nearly all of the recruitment will be done via direct invitation to women known to be at-risk. The posters are primarily meant to advertise the study with the expectation that only a few eligible women who may not have received a direct invitation for whatever reason will respond if they are interested. Women will see these posters multiple times when they return to the clinic after their booking visit (e.g., at their 12-week dating scan), so there will be opportunities for them to see and/or respond to the posters after they know they are at risk and are therefore eligible.

The Committee accepted this response.

The Committee also queried that not all women will be recruited after having responded to the poster. Some will be contacted after the booking visit, when their risk status has been

assessed but the Committee asked if these women all realise that they are at risk and if not, is the invitation letter an appropriate way of informing them

You stated that women who are identified to be at risk will be told this at their booking appointment so that screening can be discussed and booked.

The Committee accepted this response.

Lastly the Committee asked you to reconsider the need for an increase in the sample size, as by cutting out a low-risk group, it would have been expected that the planned odds ratio for gestational diabetes to increase in the remainder. This in turn would have likely to lead to the sample size to decrease but the planned odds ratio of 1.76 remains the same as it was before even through the sample size has increased.

You explained that the odds ratio used in the sample size calculation reflects the expected size of the relationship between sedentary behaviour and type 2 diabetes. This value has been extracted from a previously published meta-analysis. Thus in this case, the odds ratio does not represent the odds of developing GDM.

The Committee accepted this response.

Approved documents

The documents reviewed and approved at the meeting were:

Document	*Version*	*Date*
Copies of advertisement materials for research participants [MAM Recruitment Flyer]	1.3	20 July 2016
Covering letter on headed paper [Letter to REC (MaM) 8.8.16]		08 August 2016
Interview schedules or topic guides for participants [MAM Semi-structured interview questions V1.3 20.07.16]	1.3	20 July 2016
Non-validated questionnaire [MAM Activity Questionnaire (first trimester) V1.3 20.07.16]	1.3	20 July 2016
Non-validated questionnaire [MAM Activity Questionnaire (pre-pregnancy) V1.3 20.07.16]	1.3	20 July 2016
Non-validated questionnaire [MAM Activity Questionnaire (second trimester) V1.3 20.07.16]	1.3	20 July 2016
Non-validated questionnaire [MAM Activity Questionnaire (third trimester) V1.3 20.07.16]	1.3	20 July 2016
Notice of Substantial Amendment (non-CTIMP) [AmendmentForm_MaM]	1	11 August 2016
Other [MAM Letter of Support 24.04.16]	1.3	20 July 2016
Other [MAM Medical Records Checklist V1.3 20.07.16]	1.3	20 July 2016
Other [MAM Study Enrollment Form V1.3 20.07.16]	1.3	20 July 2016
Participant consent form [MAM Consent Form V1.2 02.06.16]	1.2	23 June 2016
Participant consent form [MAM Interview Consent Form V1.3 20.07.16]	1.3	20 July 2016
Participant information sheet (PIS) [MAM Initial Information Sheet V1.3 20.07.16]	1.3	20 July 2016
Participant information sheet (PIS) [MAM Participant information sheet V1.3 20.07.16]	1.3	20 July 2016
Referee's report or other scientific critique report [MAM Activepal Wear Instructions V1.3 20.07.16]	1.3	20 July 2016
Research protocol or project proposal [MaM Research Protocol 19July_tracked changes FY_JW (2.)]	1.3	20 July 2016

Research protocol or project proposal [MaM Research Protocol 19July_tracked changes FY_JW]	1.3	20 July 2016
Sample diary card/patient card [MAM Activpal Wear Diary V1.3 20.7.16]	1.3	20 July 2016

Membership of the Committee

The members of the Committee who took part in the review are listed on the attached sheet.

R&D approval

All investigators and research collaborators in the NHS should notify the R&D office for the relevant NHS care organisation of this amendment and check whether it affects R&D approval of the research.

Statement of compliance

The Committee is constituted in accordance with the Governance Arrangements for Research Ethics Committees and complies fully with the Standard Operating Procedures for Research Ethics Committees in the UK.

We are pleased to welcome researchers and R & D staff at our NRES committee members' training days – see details at http://www.hra.nhs.uk/hra-training/

16/SC/0355:	**Please quote this number on all correspondence**

Yours sincerely

Pp Bywater

Mr Chris Foy
Chair

E-mail: nrescommittee.southcentral-oxfordb@nhs.net

Enclosures: *List of names and professions of members who took part in the review*

Copy to: *Lynne Palmer, City Hospitals Sunderland NHS Foundation Trust*
Ms Janelle Wagnild

Appendix 11: Health Research Authority (HRA) approval letter

NHS
Health Research Authority

Ms Janelle Wagnild
Department of Anthropology
Durham University
Stockton Road
DH1 3LE

Email: hra.approval@nhs.net

04 November 2016

Dear Ms Janelle Wagnild

Letter of HRA Approval

Study title:	**The mobility and maternity (MaM) study: testing the relationship between sedentary behaviour and gestational diabetes risk**
IRAS project ID:	**196508**
REC reference:	**16/SC/0355**
Sponsor	**Durham University**

I am pleased to confirm that **HRA Approval** has been given for the above referenced study, on the basis described in the application form, protocol, supporting documentation and any clarifications noted in this letter.

Participation of NHS Organisations in England

The sponsor should now provide a copy of this letter to all participating NHS organisations in England.

Appendix B provides important information for sponsors and participating NHS organisations in England for arranging and confirming capacity and capability. **Please read *Appendix B* carefully**, in particular the following sections:

- *Participating NHS organisations in England* – this clarifies the types of participating organisations in the study and whether or not all organisations will be undertaking the same activities
- *Confirmation of capacity and capability* - this confirms whether or not each type of participating NHS organisation in England is expected to give formal confirmation of capacity and capability. Where formal confirmation is not expected, the section also provides details on the time limit given to participating organisations to opt out of the study, or request additional time, before their participation is assumed.
- *Allocation of responsibilities and rights are agreed and documented (4.1 of HRA assessment criteria)* - this provides detail on the form of agreement to be used in the study to confirm capacity and capability, where applicable.

Further information on funding, HR processes, and compliance with HRA criteria and standards is also provided.

IRAS project ID	196508

It is critical that you involve both the research management function (e.g. R&D office) supporting each organisation and the local research team (where there is one) in setting up your study. Contact details and further information about working with the research management function for each organisation can be accessed from www.hra.nhs.uk/hra-approval.

Appendices

The HRA Approval letter contains the following appendices:

- A – List of documents reviewed during HRA assessment
- B – Summary of HRA assessment

After HRA Approval

The document *"After Ethical Review – guidance for sponsors and investigators"*, issued with your REC favourable opinion, gives detailed guidance on reporting expectations for studies, including:

- Registration of research
- Notifying amendments
- Notifying the end of the study

The HRA website also provides guidance on these topics, and is updated in the light of changes in reporting expectations or procedures.

In addition to the guidance in the above, please note the following:

- HRA Approval applies for the duration of your REC favourable opinion, unless otherwise notified in writing by the HRA.
- Substantial amendments should be submitted directly to the Research Ethics Committee, as detailed in the *After Ethical Review* document. Non-substantial amendments should be submitted for review by the HRA using the form provided on the HRA website, and emailed to hra.amendments@nhs.net.
- The HRA will categorise amendments (substantial and non-substantial) and issue confirmation of continued HRA Approval. Further details can be found on the HRA website.

Scope

HRA Approval provides an approval for research involving patients or staff in NHS organisations in England.

If your study involves NHS organisations in other countries in the UK, please contact the relevant national coordinating functions for support and advice. Further information can be found at http://www.hra.nhs.uk/resources/applying-for-reviews/nhs-hsc-rd-review/.

If there are participating non-NHS organisations, local agreement should be obtained in accordance with the procedures of the local participating non-NHS organisation.

User Feedback

The Health Research Authority is continually striving to provide a high quality service to all applicants and sponsors. You are invited to give your view of the service you have received and the application

IRAS project ID	196508

procedure. If you wish to make your views known please email the HRA at hra.approval@nhs.net. Additionally, one of our staff would be happy to call and discuss your experience of HRA Approval.

HRA Training

We are pleased to welcome researchers and research management staff at our training days – see details at http://www.hra.nhs.uk/hra-training/

Your IRAS project ID is **196508**. Please quote this on all correspondence.

Yours sincerely

Steph Macpherson
Senior Asessor

Email: hra.approval@nhs.net

Copy to: *Dr Russell Hill, Durham University [Sponsor]*
Lynne Palmer, City Hospitals Sunderland NHS Foundation Trust [Lead NHS R&D]

NIHR CRN Portfolio Applications Team

IRAS project ID	196508

Appendix A - List of Documents

The final document set assessed and approved by HRA Approval is listed below.

Document	*Version*	*Date*
Copies of advertisement materials for research participants [MAM Recruitment Flyer]	1.3	20 July 2016
Evidence of Sponsor insurance or indemnity (non NHS Sponsors only) [MaM Indemnity]	1.1	20 May 2016
GP/consultant information sheets or letters [MaM GP Letter]	1.1	23 June 2016
Instructions for use of medical device [MaM activPAL Instructions]	1.1	20 May 2016
Interview schedules or topic guides for participants [MAM Semi-structured interview questions V1.3 20.07.16]	1.3	20 July 2016
IRAS Application Form [IRAS_Form_17062016]		17 June 2016
Letter from funder [MaM Funder Letter]	1.1	20 May 2016
Letters of invitation to participant [MaM Booking Information Sheet]	1.1	20 May 2016
Non-validated questionnaire [MAM Activity Questionnaire (first trimester) V1.3 20.07.16]	1.3	20 July 2016
Non-validated questionnaire [MAM Activity Questionnaire (pre-pregnancy) V1.3 20.07.16]	1.3	20 July 2016
Non-validated questionnaire [MAM Activity Questionnaire (second trimester) V1.3 20.07.16]	1.3	20 July 2016
Non-validated questionnaire [MAM Activity Questionnaire (third trimester) V1.3 20.07.16]	1.3	20 July 2016
Notice of Substantial Amendment (non-CTIMP) [AmendmentForm_MaM]	1	11 August 2016
Other [MAM Letter of Support 24.04.16]	1.3	20 July 2016
Other [MAM Medical Records Checklist V1.3 20.07.16]	1.3	20 July 2016
Other [MAM Study Enrollment Form V1.3 20.07.16]	1.3	20 July 2016
Other [MaM liability]	1.1	20 May 2016
Other [Statement of Activities]	1.3	04 November 2016
Other [Schedule of Events]	1.3	02 November 2016
Participant consent form [MAM Interview Consent Form V1.3 20.07.16]	1.3	20 July 2016
Participant information sheet (PIS) [MAM Initial Information Sheet V1.3 20.07.16]	1.3	20 July 2016
Referee's report or other scientific critique report [MAM Activepal Wear Instructions V1.3 20.07.16]	1.3	20 July 2016
Research protocol or project proposal [MaM Research Protocol 19July_tracked changes FY_JW (2.)]	1.3	20 July 2016
Sample diary card/patient card [MAM Activpal Wear Diary V1.3 20.7.16]	1.3	20 July 2016
Summary CV for Chief Investigator (CI) [CV]	1.1	20 May 2016
Summary CV for student [CV]	1.1	20 May 2016
Summary CV for supervisor (student research) [Supervisor CV]		10 November 2015
Summary, synopsis or diagram (flowchart) of protocol in non technical language [Timeline]	1.1	12 May 2016
Validated questionnaire [MaM PPAQ Questionnaires]	1.1	20 May 2016

Appendix 12: Local Research and Development (R&D) approval letters

From: "Atkinson Pauline (RLN) City Hospitals Sunderland - Research and Development Officer" <Pauline.Atkinson@chsft.nhs.uk>
Date: Monday, January 30, 2017 at 2:20 PM
To: "WAGNILD, JANELLE M." <j.m.wagnild@durham.ac.uk>, "Hinshaw Kim (RLN) City Hospitals Sunderland - Cons Obs&Gynae" <Kim.Hinshaw@chsft.nhs.uk>
Cc: "'l.gebbie@nhs.net'" <l.gebbie@nhs.net>, "Walton Eileen (RLN) City Hospitals Sunderland - Research/Clinical Teaching Midwife" <Eileen.Walton@chsft.nhs.uk>
Subject: Confirmation of Capacity and Capability at City Hospitals Sunderland NHS Foundation Trust

Dear Ms Wagnild

IRAS ID: 196508
REC Ref: 16/SC/0355
R&I Ref: 17~10

Study Title: The mobility and maternity (MaM) study: testing the relationship between sedentary behaviour and gestational diabetes risk

This email confirms that City Hospitals Sunderland NHS Foundation Trust has the Capacity and Capability to deliver the above referenced study.

Please Note: The generic patient information sheet and consent form templates must be localised using City Hospitals Sunderland letterhead and contain contact details for research staff prior to use.

Thank you for your support.

Kind Regards,
Pauline

From: Chapman, Elaine **Sent:** 24 January 2017 15:15 **To:** Waugh, Jason **Cc:** 'j.m.wagnild@durham.ac.uk'; Armstrong, Karen **Subject:** R&D 8141 | IRAS 196508 | The MaM Study-Confirmation of Capacity and Capability at The Newcastle upon Tyne Hospitals NHS Foundation Trust

Dear Dr Waugh

Confirmation of Capacity and Capability at The Newcastle upon Tyne Hospitals NHS Foundation Trust

Study Title: The MaM Study
IRAS ID: 196508
R&D Ref: 8141

This email confirms that **The Newcastle upon Tyne Hospitals NHS Foundation Trust** has the capacity and capability to deliver the above referenced study. Please find attached the signed SoA.
You now may begin work on this study, although R&D acknowledge the final greenlight may be required from sponsor.

Kind regards

Elaine Chapman
Research & Development Officer

Newcastle Joint Research Office
Research & Development
The Newcastle upon Tyne Hospitals NHS Foundation Trust
Level 1, Regent Point, Regent Farm Road, Gosforth, Newcastle Upon Tyne, NE3 3HD

Telephone (direct line): 0191 2825490
Reception: 0191 282 5959

Website: http://www.newcastlejro.org.uk/

Appendix 13: Univariate associations with outcome variables

Table A2. Univariate predictors of gestational diabetes diagnosis using simple logistic regression

Predictor variable	OR (95% CI)	p-value
Sedentary time	1.000 (0.996, 1.004)	0.83
Prolonged sedentary time	0.96 (0.60, 1.53)	0.88
Breaks in sedentary time	0.998 (0.969, 1.026)	0.87
Television time		
Less than 2 hours	1.00 (referent)	
At least 2 hours	1.89 (0.85, 4.18)	0.12
Occupational sitting		
Less than 2 hours	1.00 (referent)	
At least 2 hours	0.27 (0.09, 0.69)	**<0.01**
Not in paid work	0.78 (0.28, 2.01)	0.62
Stepping time	0.997 (0.984, 1.007)	0.56
Standing time	0.997 (0.993, 1.002)	0.27
Sleep time	1.000 (0.994, 1.007)	0.88
Age	1.000 (0.928, 1.079)	0.99
BMI	1.033 (0.965, 1.104)	0.34
Parity		
None	1.00 (referent)	
One	1.38 (0.60, 3.27)	0.45
Two or more	0.46 (0.10, 1.59)	0.26
Family history of diabetes	0.714 (0.228, 1.868)	0.52
Previous GDM	13.08 (3.23, 65.33)	**<0.001**
Neighbourhood deprivation		
Most deprived	1.00 (referent)	
Middle	0.914 (0.284, 2.509)	0.87
Least deprived	1.619 (0.610, 4.019)	0.31
Income category		
Less than £20,000	1.00 (referent)	
Between £20 and £40,000	1.57 (0.61, 4.24)	0.36
Above £40,000	1.35 (0.48, 3.87)	0.57

Table A3. Univariate predictors of fasting glucose* using simple linear regression

Predictor variable	***b* (95%CI)**	**p-value**
Sedentary time	0.00003 (-0.0001, 0.0002)	0.70
Prolonged sedentary time	0.0003 (-0.00006, 0.0006)	0.11
Breaks in sedentary time	-0.001 (-0.002, -0.0001)	**0.03**
Television time		
Less than 2 hours (referent)		
At least 2 hours	0.03 (-0.01, 0.06)	0.11
Occupational sitting		
Less than 2 hours (referent)		
At least 2 hours	-0.07 (-0.10, -0.04)	**<0.001**
Not in paid work	-0.02 (-0.06, 0.03)	0.46
Standing time	0.00002 (-0.00002, 0.0002)	0.82
Sleep time	0.0002 (-0.0004, 0.0005)	0.10
Age	0.00005 (-0.003, 0.003)	0.97
BMI	0.004 (0.001, 0.007)	**0.003**
Parity		
None (referent)		
One	-0.13 (-0.29, 0.03)	0.12
Two or more	-0.08 (-0.42, 0.27)	0.66
Family history of diabetes	0.0005 (-0.037, 0.038)	0.98
Previous GDM	-0.008 (-0.09, 0.08)	0.85
Neighbourhood deprivation		
Most deprived (referent)		
Middle	-0.001 (-0.05, 0.03)	0.75
Least deprived	-0.028 (-0.07, 0.01)	0.19
Income category		
Less than £20,000 (referent)		
Between £20 and £40,000	-0.010 (-0.048, 0.027)	0.58
Above £40,000	-0.028 (-0.068, 0.013)	0.18

* Fasting glucose was log-transformed due to positive skew

Table A4. Univariate predictors of 2-hour glucose* using simple linear regression

Predictor variable	***b* (95%CI)**	**p-value**
Sedentary time	0.0001 (-0.0002, 0.0005)	0.45
Prolonged sedentary time	0.0003 (-0.0004, 0.001)	0.43
Breaks in sedentary time	-0.0008 (-0.003, 0.002)	0.95
Television time		
Less than 2 hours (referent)		
At least 2 hours	0.02 (-0.05, 0.09)	0.61
Occupational sitting		
Less than 2 hours (referent)		
At least 2 hours	-0.08 (-0.15, -0.01)	**0.04**
Not in paid work	-0.08 (-0.18, 0.01)	0.09
Stepping time	-0.0005 (-0.001, 0.0004)	0.27
Standing time	-0.0002 (-0.0006, 0.0001)	0.22
Sleep time	0.0003 (-0.0003, 0.0008)	0.31
Age	0.003 (-0.004, 0.010)	0.39
BMI	0.004 (-0.002, 0.010)	0.22
Parity		
None (referent)		
One	-0.04 (-0.11, 0.04)	0.34
Two or more	-0.06 (-0.15, 0.04)	0.23
Family history of diabetes	-0.0009 (-0.09, 0.07)	0.83
Previous GDM	-0.09 (-0.27, 0.10)	0.36
Neighbourhood deprivation		
Most deprived (referent)		
Middle	0.02 (-0.07, 0.11)	0.66
Least deprived	0.06 (-0.03, 0.16)	0.17
Income category		
Less than £20,000 (referent)		
Between £20 and £40,000	0.02 (-0.07, 0.11)	0.65
Above £40,000	0.07 (-0.03, 0.16)	0.17

* 2-hour glucose was log-transformed due to positive skew

Table A5. Univariate predictors of blood pressure using simple linear regression

	Systolic		Diastolic	
Predictor variable	***b* (95%CI)**	**p-value**	***b* (95%CI)**	**p-value**
Sedentary time	-0.004 (-0.019, 0.011)	0.61	-0.0004 (-0.01, 0.01)	0.94
Prolonged sedentary time	0.008 (-0.022, 0.037)	0.61	0.01 (-0.01, 0.03)	0.50
Breaks in sedentary time	0.040 (-0.072, 0.151)	0.48	0.04 (-0.04, 0.12)	0.31
Television time				
Less than 2 hours (referent)				
At least 2 hours	0.56 (-2.59, 3.71)	0.73	-2.05 (-4.36, 0.27)	0.08
Occupational sitting time				
Less than 2 hours (referent)				
At least 2 hours	-0.75 (-4.02, 2.52)	0.65	-1.14 (-3.47, 1.19)	0.34
Not in paid work	-0.65 (-4.71, 3.42)	0.75	-2.17 (-5.07, 0.72)	0.14
Stepping time	0.048 (0.008, 0.088)	**0.02**	0.03 (-0.001, 0.06)	0.06
Standing time	0.013 (-0.003, 0.028)	0.10	0.01 (-0.01, 0.02)	0.27
Sleep time	0.005 (-0.019, 0.029)	0.68	-0.001 (-0.02, 0.02)	0.95
Age	0.17 (-0.12, 0.45)	0.24	0.15 (-0.06, 0.36)	0.15
BMI	0.36 (0.10, 0.62)	**0.007**	0.07 (-0.12, 0.27)	0.48
Parity				
None (referent)				
One/two	-2.46 (-5.50, 0.58)	0.11	-1.91 (-4.18, 0.36)	0.10
Three or more	-7.71 (-14.32, -1.09)	**0.02**	-1.07 (-6.01, 3.86)	0.67
Smoking status	1.54 (-2.21, 5.29)	0.42	-0.80 (-3.57, 1.97)	0.57
Neighbourhood deprivation				
Most deprived (referent)				
Middle	1.39 (-2.42, 5.21)	0.47	1.01 (-1.79 3.82)	0.48
Least deprived	2.03 (-1.79, 5.85)	0.30	2.61 (-0.19, 5.42)	0.07
Income category				
Less than £20,000 (referent)				
Between £20 and £40,000	-0.78 (-4.17, 2.60)	0.65	-0.35 (-2.88, 2.17)	0.78
Above £40,000	4.23 (0.57, 7.89)	**0.02**	2.78 (0.05, 5.51)	**0.04**

Table A6. Univariate predictors of gestational age at delivery using simple linear regression

Predictor variable	***b* (95%CI)**	**p-value**
Sedentary time	0.001 (-0.003, 0.004)	0.67
Prolonged sedentary time	0.002 (-0.005, 0.009)	0.62
Breaks in sedentary time	-0.006 (-0.03, 0.02)	0.65
Television time		
Less than 2 hours per day (referent)		
At least 2 hours per day	-0.35 (-1.06, 0.36)	0.33
Occupational sitting time		
< 2 hours per day (referent)		
≥2 hours per day	0.58 (-0.18, 1.33)	0.13
Not in paid work	0.48 (-0.46, 1.42)	0.32
Stepping time	-0.01 (-0.02, -0.002)	**0.02**
Standing time	-0.004 (-0.007, -0.0004)	**0.03**
Sleep time	0.004 (-0.002, 0.009)	0.18
Age	-0.07 (-0.13, -0.001)	**0.04**
BMI	0.02 (-0.04, 0.09)	0.52
Parity		
None (referent)		
One	-0.26 (-1.01, 0.49)	0.49
Two or more	0.11 (-0.84, 1.06)	0.81
Induction	-0.18 (-0.85, 0.50)	0.61
Smoking	-0.04 (-0.85, 0.78)	0.93
Neighbourhood deprivation		
Most deprived (referent)		
Middle	-0.18 (-1.08, 0.73)	0.70
Least deprived	0.35 (-0.56, 1.26)	0.45
Income category		
Less than £20,000 (referent)		
Between £20 and £40,000	-0.61 (-1.38, 0.15)	0.11
Above £40,000	-0.73 (-1.56, 0.09)	0.08

Table A7. Univariate predictors of birthweight using simple linear regression

Predictor variable	***b* (95%CI)**	**p-value**
Sedentary time	0.025 (-0.94, 0.99)	0.96
Prolonged sedentary time	73.22 (-39.74, 186.19)	0.20
Breaks in sedentary time	-2.31 (-9.22, 4.60)	0.51
Television time		
Less than 2 hours per day (referent)		
At least 2 hours per day	-115.04 (-315.75, 85.68)	0.26
Occupational sitting time		
Less than 2 hours per day (referent)		
At least 2 hours	116.78 (-93.40, 326.96)	0.27
Not in paid work	199.71 (-62.43, 461.85)	0.14
Stepping time	-1.98 (-4.59, 0.64)	0.14
Standing time	-0.44 (-1.43, 0.56)	0.39
Sleep time	1.32 (-0.18, 2.82)	0.08
Age	-5.64 (-24.03, 12.76)	0.55
BMI	14.75 (-2.19, 31.71)	0.09
Parity		
None (referent)		
One	170.33 (-39.90, 380.55)	0.11
Two or more	276.84 (17.27, 536.41)	**0.04**
Smoking	-208.30 (-444.33, 27.72)	0.08
Sex of baby	-215.89 (-407.51, -24.27)	**0.03**
Gestational age at delivery	227.49 (193.66, 261.33)	**<0.001**
GDM diagnosis		
No (referent)		
Yes	-414.6 (-662.5, -166.7)	**0.001**
Neighbourhood deprivation		
Most deprived (referent)		
Middle	3.13 (-243.8, 250.0)	0.98
Least deprived	136.1 (-113.5, 385.7)	0.28
Income category		
Less than £20,000 (referent)		
Between £20 and £40,000	-183.19 (-400.44, 34.06)	0.10
Above £40,000	-55.29 (-286.74, 176.16)	0.64

Table A8. Univariate predictors of macrosomia using simple logistic regression

Predictor variable	**OR (95% CI)**	**p-value**
Sedentary time	1.00 (0.996, 1.004)	0.94
Prolonged sedentary time	1.30 (0.81, 2.11)	0.28
Breaks in sedentary time	1.02 (0.99, 1.05)	0.24
Television time		
Less than 2 hours per day	1.00 (referent)	
At least 2 hours per day	0.55 (0.20, 1.32)	0.20
Occupational sitting time		
Less than 2 hours per day	1.00 (referent)	
At least 2 hours per day	1.26 (0.49, 3.32)	0.63
Not in paid work	2.13 (0.73, 6.13)	0.16
Stepping time	1.003 (0.992, 1.013)	0.59
Standing time	0.999 (0.995, 1.004)	0.87
Sleep time	1.005 (0.998, 1.012)	0.16
Age	0.98 (0.90, 1.06)	0.60
BMI	1.04 (0.97, 1.12)	0.23
Parity		
None	1.00 (referent)	
One	1.62 (0.65, 4.30)	0.31
Two or more	1.45 (0.44, 4.54)	0.52
Recruitment site	1.17 (0.52, 2.62)	0.71
Gestational age at delivery	2.12 (1.52, 3.15)	**<0.001**
GDM diagnosis		
No	1.00 (referent)	
Yes	0.16 (0.01, 0.81)	0.08
Smoking status		
Sex of baby	0.63 (0.26, 1.44)	0.28
Neighbourhood deprivation		
Most deprived	1.00 (referent)	
Middle	0.74 (0.20, 2.18)	0.62
Least deprived	1.49 (0.53, 3.82)	0.43
Income category		
Less than £20,000	1.00 (referent)	
Between £20-40,000	0.69 (0.25, 1.89)	0.47
Above £40,000	0.92 (0.33, 2.54)	0.88

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