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Developing and Testing a Low Language Demand Test of Episodic Memory in Autistic Children.

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Thesis Abstract

Developmental research on memory in autism suggests difficulties in episodic memory (EM), specifically recalling fewer or less specific memories of previous encounters due to several facets of memory contributing to these difficulties. The methodological approach of much of this research requires the conscious recollection of past experiences, which proves difficult to assess without using language. This offers a challenge and potential confound for studies of episodic memory in autism, where language skills may be affected. Therefore, this thesis aimed to develop and test a low language demand test of EM to explore EM in neurotypical and autistic children across a wide range of ages to ascertain whether this would lead to a revaluation of their capabilities.

Findings across four experiments developed a reliable, valid measure of episodic-like memory (because it omits the experiential component requiring conscious recollection) that was less reliant on spoken communication. Findings suggest that neurotypical and autistic children across a wide variety of ages can recall highly specific episodic events anchored to spatial and temporal contexts. However, a particularly pertinent finding was that while EM was unrelated to autism characteristics, it depended on visuospatial working memory for autistic children, suggesting that they achieve similar performance through alternative means. Another significant finding was that using the What-Where-Which occasion test, there was no interdependency between full EM and its binding components, illustrating that the ability to recall specific past events in a particular context and place does not depend on the ability first to bind what-where or what-which information.

The findings highlight several contradictions with previous findings, suggesting that this new approach offers insights into the mechanisms of EM and the nature of memory difficulty in autism, which would not be observable with standard approaches.

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Declaration

At the time of submission, no content from this thesis has been published, nor is it under review for publication.

Statement of Copyright

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I would also like to express my heartfelt gratitude to all the participants who took part in these experiments, especially the children. Working with you was an absolute joy, as your warmth and humour made the experience both welcoming and entertaining. Thank you for being such a delight to work with.

Finally, I dedicate this thesis to my younger self, the girl who once despised school and left with no qualifications but loved learning. This achievement is not just mine but a reminder that no child should slip through the cracks. Every child deserves the chance to learn and grow, regardless of their background or circumstances. I hope this serves as a beacon of hope to others who may have faced similar obstacles; we can do this!

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1 General Introduction

The extraordinary and mundane encounters that punctuate our daily lives undoubtedly define who we are. Despite this, rarely might we question what our lives would look and feel like without this fundamental capacity or ponder how it developed in the first place. The current thesis is concerned with episodic memory – defined as retrieving past experiences anchored to a specific spatial and temporal context. This first section outlines how we have defined episodic memory and, as a result, shaped our understanding of how and when it develops in children. Subsequently, it discusses memory in autism, a neurodevelopmental condition defined by social communication difficulties with marked disruption in episodic abilities, with explanations for these findings rooted in memory theories. It also outlines how assessing episodic memory in Autistic and non-autistic populations remains a formidable challenge due to reliance on heavily verbal methodologies resulting from current definitions of episodic memory and their focus on the individual's experience rather than on the individual contents of the memory itself. We discuss this issue in the context of related developments in language and social cognition. Finally, taking inspiration from content-based memory assessments, the thesis introduces a novel non-verbal episodic memory task. It explores its development using adults, and its application in non-autistic and autistic children, highlighting its potential usefulness to progress our understanding of the vulnerabilities and capabilities of episodic memory in children across various ages, neurodivergent or otherwise.

1.1. Defining Episodic Memory

Episodic memory (EM) refers to the capacity to recollect personally experienced specific life events. It plays a central role in our lives, enabling us to re-experience past events and pre-experience future ones, a capacity critical to human cognition (Atance & O'Neill, 2001;

Coughlin et al., 2014; Nelson & Fivush, 2004; Tulving, 1983) and arguably a unique adaptation of our species (Suddendorf & Corballis, 1997; Tulving, 2005).

Episodic memory is one of the two sub-systems within the declarative memory system (i.e., memory available to conscious recall): the other is semantic memory (Squire et al., 1993; Squire & Zola, 1996; Tulving, 1972, 1985). Whilst semantic memory is a store of knowledge of facts, episodic memories are memories of personal experiences and events from our past (Tulving, 1983). In its original inception, Tulving (1972) defined episodic memory as a memory system that "receives and stores information about temporally dated episodes or events, and temporal-spatial relations among these events" (Tulving, 1972, p. 385). In other words, memory for *what* happened, *where,* and *when* (Clayton & Dickinson, 1998).

Later, Tulving developed a more specific definition of episodic memory that involved the ‘autonoetic’ character of EM (i.e., an awareness of one’s existence in relation to remembering a past event) (Tulving, 1985) and the concept of "chronasthesia", (i.e., being aware of the past and the future) (Tulving, 2002a, 2005). Together these allow one to project oneself toward both the past and the future to re-experience the spatiotemporal context of the event in question – termed mental time travel (Suddendorf & Busby, 2005). Autonoetic consciousness constitutes a necessary condition for episodic memory because it gives rise to the sense of self-recollection in the mental ‘re-living’ of a past event. Recollection is the ability to recall qualitative information about a past event (Thakral et al., 2017). Past episodes are the constituent aspects of an experience bound with the spatial and temporal context into one unit (what happened, where, when, who, etc.). An example of episodic remembering might be remembering that I saw the neighbour’s dog when locking the front door this morning. The defining property is in the subjective state of awareness that accompanies an experienced event – we inherently recollect ourselves as the rememberer (Conway, 2009) with a distinct ‘feeling of remembering’. By contrast, simply knowing that an event happened in the past would constitute semantic memory. Semantic memory identifies with noetic consciousness, an awareness of the past limited to feelings of familiarity/knowing not featuring specific representations of the self (Conway, 2009). An example of semantic memory might be '*knowing'* that London is the capital of Great Britain, as is the knowledge that I have visited London many times (without experiencing any personal recollection of the event details). These examples are "timeless", so recalling the time and the context of learning is not required (Eichenbaum, 2004, p. 110). Thus, episodic recollection involves relational binding of the constituent aspects of an experience with the spatial and temporal contexts, self-projection: putting oneself back into the personal past, and finally, the ability to reconstruct and recombine the memory for retrieval success.

This focus on the experience of remembering makes examining episodic memory capacity without language extremely challenging. In the next section, we explore current theories of episodic cognition and how much of the developmental literature is concerned with conceptualist notions of an individual's experience, which may lie in the narratives of experience rather than in the contents of the memory itself (Tulving, 2005).

1.2. Theoretical Perspectives and Assumptions

Three theoretical frameworks to account for the development of episodic memory are guiding developmental research, predominantly the conceptualist account and less so two forms of minimalism [episodic-like and Kantian minimalism] (for reviews of these perspectives, see Clayton & Russell, 2009; Russell & Hanna, 2012).

1.2.1 Conceptualist Framework

As its name suggests, the conceptualist framework asserts that considering memory as episodic requires particular conceptual abilities beyond merely recalling an event's spatiotemporal content (Tulving, 2001). In this framework, autonoetic consciousness mediates EM, which in turn is dependent upon the emergence of several interrelated cognitive abilities: the concept of self (self-awareness), metarepresentation (necessary for theory of mind abilities), and achievements in temporal cognition (i.e., the ability to represent the locations of events in time concerning the self) (for discussions see Lind & Bowler, 2008; Lind, 2010; McCormack, 2015). Thus far, the aggregate effects of these positive developments contribute to the emergence of episodic cognition. First, they allow the memory to become self-knowing, so the person remembering an experience does so with the complete self-knowledge that they are 're-experiencing' the initial event (Lind, 2010). This view places the *subjective experience* of remembering at the core of EM. Hence, without the cognitive abilities to support autonoetic consciousness, there can be no EM functioning (Tulving, 2002b, 2002a; Wheeler et al., 1997; but see Russell & Hanna, 2012.

In typical development, these cognitive abilities emerge at different times and do not become fully functional until 4 to 5 years of age (for review, see Lind, 2010). For example, developmental findings show that although children pass tests assessing a concept of the self by the age of 2 years (Amsterdam, 1972), this understanding does not incorporate the past, present, and future states until the child is about 4-years of age, when a temporally extended-self emerges (Povinelli et al., 1996, 1999). Povinelli and colleagues (1996, 1999) used a delayed self-recognition test (i.e., an adapted version of the classic mirror self-recognition test that includes a temporal element) to measure temporally extended self-awareness. In the task, the authors videotaped children between the ages of 2 and 4 years old playing a game in which they tried to find stickers hidden under inverted cups. Next, the experimenter surreptitiously placed a sticker on the child's head during the game. Following this, the experimenters presented children with video playback (3-min-old) for the entire session. They reasoned that a more advanced level of self-awareness with temporal continuity would require children to causally relate their current state (i.e., surprise sticker on the head) to prior experience of the event depicted in the video (Povinelli et al., 1996, 1999). Thus, children should reach up to remove the sticker from their heads. Their results showed hardly any 3-year-olds (25%) reached up to remove the sticker, but practically all four-year-olds showed recognition (75%).

In contrast, none of the two-year-olds showed recognition. Povinelli and colleagues (1996, 1999) concluded that younger children fail in this task because they lack a temporally extended self-awareness (but see Suddendorf, 1999 for an alternative explanation). It is this ability, the authors argue, that allows the child to integrate the past with the present self, requiring metarepresentation abilities that would enable episodic cognition. Similarly, Perner and Ruffman (1995) argue that metarepresentation abilities are vital to EM, attributed to a developing understanding of the seeing = knowing rule that requires a theory of mind - emerging at around 4- to 5 years of age (Perner & Ruffman, 1995).

These results have led to the supposition that EM 'emerges' relatively late in development (e.g., Nelson, 1992; Perner & Ruffman, 1995; Wheeler et al., 1997) and is a uniquely human capacity (Tulving, 2005). This understanding creates a dilemma in the literature because it excludes much research exploring infants' early memory capabilities. These studies have shown that infants can encode and retain highly detailed hippocampal-dependent event information (see Mullally & Maguire, 2014 for review). For example, elicited (immediate) and deferred (after a delay) imitation studies have demonstrated that infants as young as 9 months are adept and flexible at forming enduring memories of events, recalling not only the actions but the temporal order of the sequences themselves (see Mullally & Maguire, 2014). The reasoning, then, is that although these demonstrations show early memory competence, they make no explicit reference to recollective experiences. They fall short of the limitations built into Tulving's (2005) later definition of EM.

But to take this as evidence that children do not form episodic memories before the transitional age of 4 years could be problematic. In addition to early infant memory capabilities, we know from studies focusing on age-related changes in children's memory that the ability to describe their memories verbally improves dramatically (Fivush et al., 1992; Howe et al., 1994; Peterson & Rideout, 1998; Pillemer et al., 1994). Moreover, studies examining the mechanisms underlying childhood amnesia, the inability to remember episodic experiences occurring during the first three years of life, have found that verbal memory performance lags substantially behind nonverbal memory performance (Simcock & Hayne, 2002). Simcock and Hayne (2002) found that despite children being linguistically competent and possessing the productive language skills to report on a memory encoded pre-verbally, they could not translate this into words and continued to rely on their nonverbal skills (behavioural re-enactment) during a memory interview. This finding demonstrates that young children could remember, but this ability only came to the fore with nonverbal assessment methods. Had their performance been measured using language alone, it may have been rendered substantially poorer.

Hence, children's memory for past events unequivocally improves throughout childhood (Bauer & Fivush, 2013) with increases in autonoetic awareness (Tulving, 2005; Wheeler, 2000), locating events in time (Friedman, 2013) and place (Lourenco & Frick, 2014). This has led others to argue; instead, a more parsimonious explanation is that these basic memory processes are a developmental precursor of a mature EM system (Burns et al., 2015; Clayton & Russell, 2009; J. Russell & Hanna, 2012). One which improves rather than emerges.

1.2.2 The minimalist perspective of episodic abilities

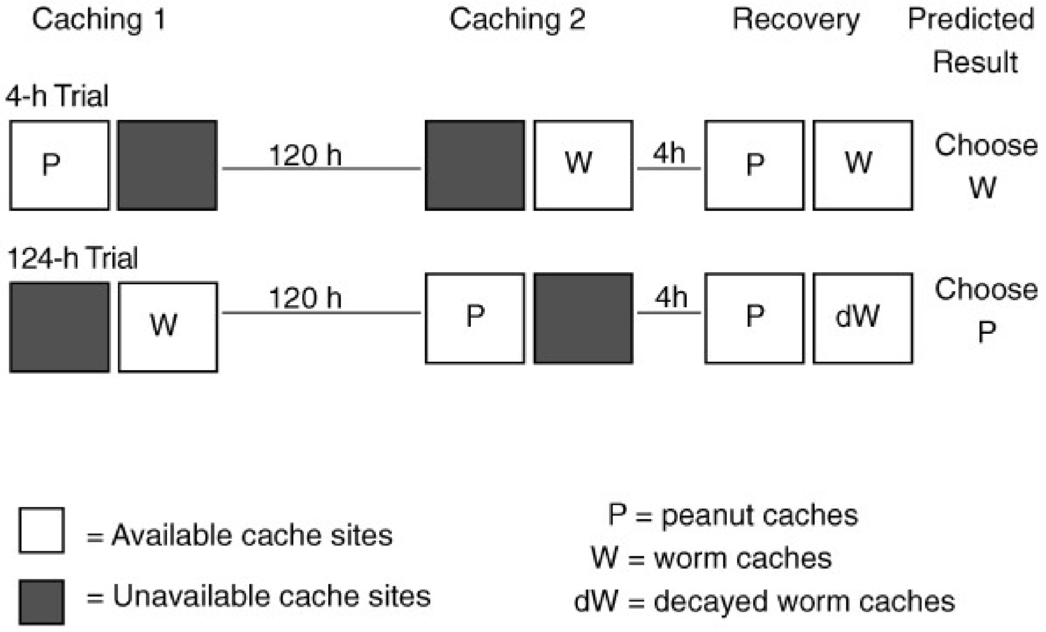
In contrast to the conceptualist's account is the minimalist theoretical framework. Shaped by Tulving's original view of EM, it assesses the content of the memory instead of its subjective phenomenology; memory for *what* happened, *where* and *when*

(Clayton & Dickinson, 1998). Notably, though omitting a demonstration of autonoetic consciousness, the conception of episodic-like memory encompasses more than merely the content of what, where, and when (Clayton, Bussey, Emery, et al., 2003). Furthermore, the minimalist framework requires that memory demonstrations are: (1) based on a single experience; (2) integrated, so the content, spatial and temporal elements bind into one holistic memory; and (3) can be flexibly deployed, so the behaviour is not fixed or determined by current motivational state (Clayton et al., 2003).

Clayton and Dickinson (1998) first introduced a content-based approach to studying episodic animal memory using the what-where-when criterion. A test of memory for what item was hidden, where, and when. In their seminal study, the authors used the caching behaviour of scrub jays as evidence of episodic-like memory for events (episodic-like because it omits the experiential qualities of EM). The experiment aimed to demonstrate that scrub jays could recall what they hid (wax worms or peanuts), its spatial location (where; caching trays), and the temporal element (how long ago the caching took place; 120 hours vs 4 hours) (see Figure 1.1). As shown in Figure 1.1, in 4-hour trials, birds initially cached peanuts in Tray 2, then 120 hours later cached wax worms in Tray 1. Following a further 4 hours, the birds were allowed to search both trays to recover either worms or peanuts. On these trials, birds recovered their preferred food (i.e., wax worms).

In contrast, in 124-hour trials, the scrub jays initially cached wax worms in Tray 1, then 120 hours later cached peanuts in Tray 2. After another 4 hours, the birds could search both trays to recover their cache. Importantly during pre-training trials, birds experienced either the ‘degrade’ condition, where worms degrade and become unpalatable after 124 hours, or the replenish condition, where worms were replaced with fresh ones. Consequently, the birds in the degrade group learned that worms become inedible throughout 124 hours but not when the caching event took place at 4 hours. Over a long delay, therefore, birds in the degrade group preferred to recover peanuts over a long wait. To test whether the birds could remember what they cached, where and when, they were presented with empty caching trays relying solely on memory. Results showed that the birds pre-trained in the degrade group recovered peanuts at long delays despite worms being their preferred food. This illustrated they had integrated the what-where-when information to flexibly guide their behaviour to retrieve wax worms or peanuts depending on how long ago the caching took place. Thereby fulfilling the behavioural criteria by forming an integrated memory that bound the identity of the food stored (waxworms vs peanuts) with the location it was cached (trays) and 'when' caching took place to recover food (Clayton, Bussey, Emery, et al., 2003).

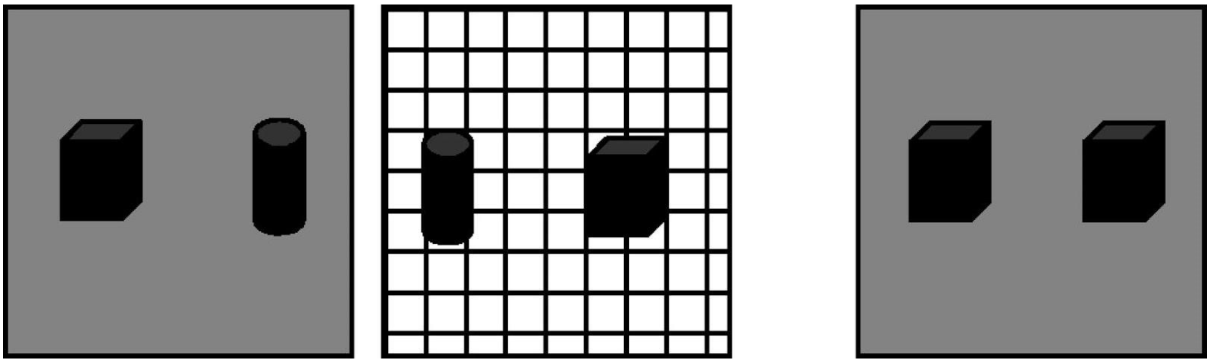
Figure 1.1 *Schematic of the What-Where-When task (Clayton & Dickinson, 1998)*



Note. The schematic figure illustrates each caching tray's experimental conditions and contents presented at different 4-h and 124-h training and trial phases. In the 4-hour training trial example, birds were allowed to cache peanuts in trial-unique, visually distinguishable caching trays (left). After a 120h delay, birds buried waxworms (their preferred food) in a trial unique tray (right). Following a short delay of four hours, when allowed to recover their cache, the birds chose to recover waxworms, their preferred food. However, in the longer interval trial (124h), the opposite pattern is observed because the birds learn that their preferred food (waxworms) perishes after a long but not short delay. In the final extinction test, no food is present after 4 or 124 hours, requiring the bird to rely on memory alone. At short intervals, the bird searched for waxworms, but for peanuts at long intervals, demonstrating recall for *what* they cached (peanuts vs waxworms), *where* (caching tray) and *when* (how long had passed between caching and recovery; long vs short delay). Pretraining involved two conditions; degrade condition, where worms were unpalatable after 124 hours, and a replenish condition, where stored worms were replaced with fresh ones before recovery. The image is taken from Clayton and Dickinson (1998). Nature, 396, 272-298 (1998).

An alternative content-based approach is used by Eacott and Norman (2004). In their influential task, the content is broken down into what happened, where it happened and on which occasion it occurred, using the context it was encoded in to separate two highly similar events (henceforth WWWhich). In the WWWhich task (see Figure 1.2), they presented rats with two different objects in different orders (first, second) and different spatial locations (left, right) in two contextually (visual and textural) unique events. A unique event, in this case, is the combination of these factors to differentiate the novel from the familiar object.

Figure 1.2 *Schematic of the Integrated Object, Place, and Context Task*



Note. The figure illustrates a schematic representation of the two encoding phases with two different objects and a test phase where they are exposed to two copies of the same object in a sample phase. The novel combination of object and context is the object on the right in the example. Adapted from '*Integrated memory for objects, place, and context in rats: a possible model of episodic-like memory*?', by Eacott & Norman (2004) Journal of Neuroscience, 24, p. 1949. Copyright 2004 by The Society for Neuroscience.

In the first encoding phase, rats are presented with two different objects, one on the left and the other on the right of the arena in context one. After exploring the objects in this context, the rat is removed for a brief delay. In the second encoding phase, the rat is returned to the arena, exposed to context two, and presented with the same objects as phase one, switched to the opposite location. For example, an object on the left in the first context would be on the right in the second context. After variable delays, the rats return to the arena (configured to one of the previously seen contexts) with two identical copies of the same object on the left and right of the arena, one of which will be novel and the other familiar. Critically, suppose the rat has encoded the two events as being separate. In that case, it should demonstrate a novelty preference for the object it has seen before but never in that location in that context. This would illustrate an integrated memory for what happened, where, and which occasion, thereby fulfilling the behavioural criteria for episodic-like memory set out by Clayton et al. (2003).

Results showed that rats spent longer exploring the integrated and novel combination of what they saw, where they saw it, and on which occasion it was seen. Demonstrating they can distinguish the novel from the familiar object and can easily do this at delays of up to one hour (Eacott & Norman, 2004). Importantly, their experiment did not require substantial pre-training, making it a powerful demonstration of episodic-like memory. Eacott and Norman (2004) argued that the 'when' element is a temporal identifier used as an "occasion-setter", a term used to describe setting the occasion for an operant response to occur. Importantly, occasion setters do not elicit the relevant response. Instead, the presence versus absence of an occasion setter determines the evoked response (Bouton, 2010). For example, opening up one’s laptop might not elicit writing or compel one to write. It does, however, allow or set the occasion for writing to occur. Thus, in the context of memory, the ‘when’ would set the occasion, but the context embedded in the memory disambiguates highly similar experiences. An illustration of this might be remembering having read a book this morning whilst sitting on the chair at home instead of sitting on the same chair but watching TV in the evening. Both events entail a recollection of ‘when’ it occurred (same day). Still, to discriminate the two experiences, it is temporal context, that is, the features of an experience that occur at the time it is experienced, which make the memories specific and distinct experiences.

Consequently, while the memory of an event need not entail recollection of when exactly it occurred, it involves the inference of time via context using reconstruction (Friedman, 1993). It is a malleable and fallible process. Eacott and Norman (2004) thus concluded that ‘which occasion’ could equally be used in place of ‘when’ as one of the behavioural triads in content-based memory. On this view, the stored information must be constructed using context that enriches and recombines to disambiguate memories.

Further examination of Clayton and Dickinson’s (1998) original WWW task shows each caching tray was made visuospatially distinct by a surrounding structure of Lego bricks. This was in conjunction with the ‘when’ element (relative time since caching), which may equally have helped with encoding, retrieval, or both. Thus, ‘when’ and ‘which’ are intertwined and used in WWW and WWWhich occasion tasks. Essentially, making both tasks highly similar in that temporal context is vital for episodic-like memory. Where they differ is in their application and testing.

In What-Where-When tasks, the isolated triad of behavioural criteria requires integration for an appropriate response. Still, one can equally assess the disparate elements through search errors and infer binding failures. For instance, the inability to recall the ‘what’ feature might suggest difficulty integrating identity with location and time. In contrast, in WWWhich tasks, the temporal context *determines* the correct response by requiring the memory to be reconstructed (using time as an occasion setter) because it relies on disambiguating highly similar experiences. Thus, a strength *and* a caveat of WWWhich tasks are that it is impossible to infer memory for the separate elements unless they are expressly assessed. For example, consider the study by Eacott and Norman (2004), failure at test to explore the novel combination of object, location and context does not allow one to infer that memory for the object’s identity or any other features were not recalled because the learning and assessment of the memory require holistic reconstruction, with failure also holistic.

Cheke and Clayton argued that a caveat of WWWhich tasks is that the ‘which’ element is inextricably confounded by ‘what’ and ‘where’ unless ‘when’ is used. But they also agree that its strength lies in it being more in line with human memory (Cheke & Clayton, 2010). This is undoubtedly true when considering incidental memories, such as those formed throughout everyday life. Contextual cues often define a particular occasion rather than remembering the specific day, date, or time a past event occurred. The temporal information associated with a memory for a particular event is prone to errors (Friedman, 1993; Schacter & Addis, 2007). And even in their original task, the context was important to distinguish visually one caching event from another. Each approach, with its advantages and caveats, highlights the generative nature of episodic memory, one that need not explicitly rely on time and one where time alone is not always sufficient.

1.2.3. Kantian minimalism

In Kantian Minimalism, an alternative to episodic-like minimalism, there is the added requirement of the first-person perspective (see Clayton & Russell, 2009; Russell & Hanna, 2012). Kantian minimalism makes some assertions over the underlying phenomenology associated with memory. In particular, it demonstrates the 'who' element illustrative of self-conscious awareness (i.e., self as the experiencer) (see Russell & Hanna, 2012 for discussion). Without this, Burns et al. (2016) argue it does not necessarily mean they recognise themselves as the person that experienced the event (Burns et al., 2016). To do this would require children to bind themselves to WWW memory. Burns et al. (2016) used a Kantian minimalist form of the WWW task, which requires first-person perspective taking – the addition of the **who** element. The authors reasoned that success on their task requires children to embed their current mental representation within a past one – requiring second-order reasoning abilities. The experimenter instructed the children to listen for video sounds while videotaped in the task. At that precise moment, animal noises sounded, two trees lit up (at either side of the child). These lights either lit up simultaneously (both together) or sequentially (left-right / right-left), depending on the condition. After a 24-hr delay, the child was shown playback of the video from three different perspectives (behind/above/front) and asked to choose the video in which they thought they were present (note: the child is not visible in all perspectives). Once the child chose a view, the child also justified their choice – an appropriate justification would be referring to the temporal order of the lights. Crucially, the camera positions that showed above and the front perspectives can only be solved using episodic retrieval processes – because these are different perspectives to that at encoding. Results showed that only children older than 4.5-year-olds could use spatiotemporal cues to infer their presence in the video as the person who experienced the event. The viewing angle did not affect performance. Moreover, their performance on the WWW-who EM task correlated with a second-order theory of mind tasks. This correlation held even when age and verbal ability were partialled out. This finding is consistent with the existing literature outlined earlier that children's concept of themselves does not show continuity across time (i.e., where the self extends across time and space: past, present, future) until four years of age (Povinelli et al., 1996; Povinelli et al., 1999). It is also consistent with previous research that EM abilities emerge around four years with other cognitive capacities such as theory of mind abilities (Perner & Ruffman, 1995). The authors concluded that findings demonstrate the emergence of a more mature EM.

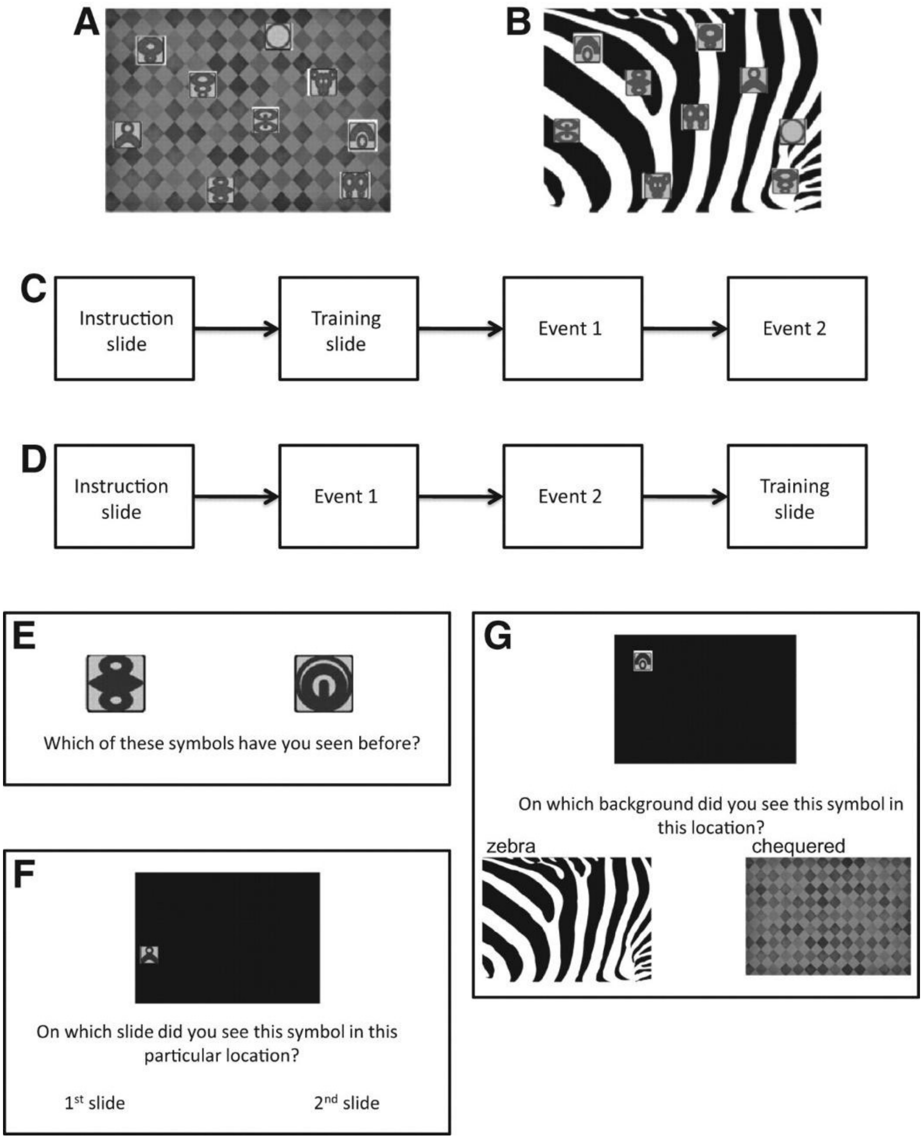
To summarise, it is uncontroversial that episodic memory depends on the support of several interrelated cognitive capacities, including a sense of self, achievements in temporal cognition (an understanding of a temporally extended self across time), autonoetic consciousness and theory of mind abilities. However, to increase our knowledge and generalisability of the findings for less verbal individuals, such as young children and children with neurodevelopmental conditions (such as autism, where social communication difficulties are integral to a diagnosis), we need to develop procedures relying less on the experiential qualities of episodic memory. Thus, to overcome these challenges, we can expand our use of novel behavioural methodologies, such as content-based episodic task,s because they allow a nuanced understanding of memory, given the developmental, social, and cognitive challenges at play. It is important to emphasise that this stance does not preclude the richness, complexity and quality of memories accessed using language. Instead, it accommodates for challenges in language and communication that, as we will see in subsequent sections, may affect the ability to provide coherent narratives about experienced events.

1.3 Application of Content-based tasks in humans

All three methodologies have since been adapted for humans (Cheke & Clayton, 2015; Cuevas et al., 2015; Easton et al., 2012; Hayne & Imuta, 2011; Holland & Smulders, 2011b; Mazurek et al., 2015; Newcombe et al., 2014; Plancher et al., 2008, 2010).

Holland and Smulders (2011) used a hide-and-seek procedure to investigate whether the what-where-when (WWW) task was suitable for accessing EM in adult humans. The process involved adults hiding two different coin types over two consecutive days, and (1) an unexpected question about a context unique to the encoding session (e.g., was it raining?); and (2) the mental time strategy used to recall the *what-where-when (*WWW*)* elements of the task. The authors found that accuracy on the WWW task predicted performance on the unexpected question test and that a strategy of "*remembering*" rather than "*knowing*" was overwhelmingly reported. This evidence suggested that the WWW memory task is valid for accessing EM in humans. Easton et al. (2012) obtained similar results using the what-where-which (WWWhich) occasion memory task. In their paper and pen task (see Figure 1.3), adults sequentially viewed two events: in each event, they were presented with nine different objects in separate locations set against a distinctive background (event 1). Following a 1-min delay, the experimenter introduced the second event. The second event consisted of the same objects as in event one but presented at different locations (though the possible locations remain the same) against a new background. The test phase followed the two encoding events: nine questions in three blocks comprising what questions, WWWhen questions, and WWWhich questions. For the first block of what questions, participants would be presented with a novel and familiar item and asked, "Which of these symbols have you seen before?" (Fig 1.3: E). For WWWhen questions, participants would be shown an item at a particular location but set against a plain background and asked, "on which slide did you see this symbol in this particular location (options: 1st or 2nd; Fig 1.3: F). Finally, for WWWhich questions, participants were again shown an item at a specific location but set against a plain background and asked, “on which background did you see this symbol in this location (options: zebra or chequered; Fig 1.3: F). For each question, participants also had to indicate the experience associated with their decision (remember, know, or guess) and the confidence ratings of the answers given (scale 1 to 5). Results showed that only one type of episodic-like memory question (WWWhich) was accurately answered using only recollection (strategy of remembering); WWWhich. While recollection (remember) or familiarity-based mechanisms (knowing) were employed when accurately answering WWW questions. This finding, the authors argue, suggests what-where-which tasks are less likely to be solved non-episodically (Easton et al., 2012).

Figure 1.3 *Schematic of the Integrated Object, Place, and Context Task in Adults*



Note: The image is taken from (Easton et al., 2012). Learning & Memory, 19, 146-150 (2012).

1.3.1 Using minimal WWW (or WWWhich) tasks to assess EM in non-autistic children

Even fewer studies have investigated EM abilities using WWW or WWWhich memory tasks in children. Those who have suggested that children's EM capabilities may improve between 2.5 to 5 years (Burns et al., 2015, 2016; Hayne & Imuta, 2011; Newcombe et al., 2014). Thus, 'emerging' earlier than previously hypothesised (e.g., Hayne & Imuta, 2011; see Russell et al.,2015 and Russell & Hanna, 2012 for discussions).

Hayne and Imuta (2011) used behavioural and verbal recall measures of performance in a hide-and-seek version of the WWW task. The procedure involved 3- and 4-year-old children hiding toys in three disparate locations in their own homes. After a 5-minute retention interval, the experimenter asked children to verbally recall the WWW elements of a hiding event (i.e., what toys they hid, where they hid them, the room's particular location, and the rooms' order visited). Following this, they could recall the same information behaviourally except the 'what' component. Results showed that 3-year-olds were significantly worse than 4-year-olds in the verbal recall task but showed the equivalent performance to 4-year-olds on the behavioural recall task. An age-related difference, however, remained for the temporal element. They also found that children performed better on the 'where' component than the 'what' by 4 years of age – suggesting that the binding of the individual elements develops gradually with some associations coming 'online' earlier than others (but see Cuevas et al., 2015 for opposite pattern). Arguably, the improvement in retrieval (for behavioural recall) could be explained by having first verbally recalled the WWW elements – rendering memories more accessible on the subsequent behavioural trial. However, it may also suggest that children can form episodic memories before their hypothesised emergence at 4- to 5 years of age by reducing language confounds. It is noteworthy to mention that a modified version of this task did not find better performance between verbal recall measures and a recognition procedure that involved nonverbal pointing at clipart images depicting the what and where information (see Cuevas et al., 2015).

Cuevas et al. (2015) used a modified version of the Hayne and Imuta (2011) hide-and-seek task within a WWW paradigm to examine age-related differences in the binding for the individual episodic: what-where-when elements, this time in a lab-based setting. Using a longitudinal design, the authors examined episodic-like memory and episodic future thinking in 3- and 4-year-olds. The procedure also involved a nonverbal pointing recognition task. Results indicated that 3-year-olds were less able to accurately recall the 'when' information of a hiding event, but this ability substantially improved by 4 years. While the opposite pattern is seen by Hayne and Imuta (2011), the temporal element ‘when’ remained less robust than ‘what or where. However, because the two studies differ in the nonverbal measures used, it is difficult to conclude whether nonverbal actions enhanced memory performance.

In another study, using contextual information rather than temporal order of the rooms visited (WWWhich task), Newcombe et al. (2014) found age-related improvements in context-based EM. This procedure involved children ranging from 15 months to 72 months searching for two toys in two rooms using a modified version of a rat study by Eacott and Norman (2004). The task required children to recall by searching where (i.e., in a cylinder vs box) and in which context (Rainbow vs Cloud castle room) they had hidden a toy. Children as young as 34 months were successful on this task (i.e., performing above chance levels set at 25%), and performance was almost perfect by five years. Moreover, even 21-month-olds were able to reliably disambiguate between two containers (where) by room context. The authors concluded that children’s episodic abilities show age-related improvements, which may be specific to children’s binding skills.

As previously highlighted, integrating the individual elements (what-where-when or which context) into a cohesive memory is crucial to infer episodic-like memory abilities in minimal WWW memory tasks (Clayton et al., 2003). Given that the design of the paradigm explored the *integrated* memory of what-where-which elements, it is difficult to draw any definite conclusions regarding the binding of the individual features by examining the search errors alone. It is noteworthy to mention that, in general, in WWW tasks, associations have been inferred from the types of recall errors individuals made (e.g., incorrect occasion/object/location errors). However, this can be problematic. For example, Holland and Smulders (2011) reported that adults correctly remembered the object/location but not the occasion. Thus, a task precisely manipulating these associations would be informative.

We have illustrated that children pass these episodic-like tasks at younger ages than previously hypothesised (e.g., Perner & Ruffman, 1995; Tulving, 2002, 2005).

1.3.2 Summary

We have established that a framework that relies heavily on the phenomenological experience of EM, accessed through verbal methodologies, can hamper young children’s task performance (e.g., Hayne & Imuta, 2011; Simcock & Hayne, 2002) and restricts testing to one test format only; verbal reports. This makes good performance impossible without verbally reporting the consciousness of one's memories. Relatedly, we have also highlighted that an inability to verbally say the conscious aspects of the past does not equate with a lack of episodic abilities. On the contrary, a proliferation of research has demonstrated infants' remarkable feats of memory that only fall short of being 'episodic' because of the definitions built into what it means to recall episodically (for review, see Mullally & Maguire, 2014). Accordingly, this unhelpfully prevents investigating EM at different levels across development because its existence is inextricably tied to concepts such as autonoetic awareness and mental time travel, abilities that pose a formidable challenge to assess without language. Taken together, this suggests that EM should not be conceptualised as a skill that is acquired abruptly at one specific period in development. Instead, its development is gradual, with improvements in cognition and language. This view preserves the capabilities of young children without discounting the enormous enrichment development brings to its phenomenology.

One way to deepen our understanding of EM is to investigate the presence of different components in memory, which consists of retrieving what happened when/which occasion and where permitting the ability to "re-experience episodes". Such investigations must negotiate the difficulties inherent in verbal assessments because of the fundamental challenges young children face when relying on language alone. Behavioural methodologies such as content-based tasks hold considerable promise as valuable measures for exploring the development of episodic memory. Studies employing a content-based approach have successfully tracked the emergence of episodic memory across childhood (Hayne & Imuta, 2011). However, although the primary focus of episodic-like memory tasks has been to make them behavioural, critically, the outcome measures in human versions tend not to be. To this end, despite being behavioural tasks, they are not minimally language-based – hence still constrain work with less verbal individuals, such as young children and children with neurodevelopmental conditions. As you will see in the forthcoming sections, autism is a neurodevelopmental condition stratified based on several difficulties in social communication, including difficulties in back-and-forth conversation; and using language appropriately in a specific context or situation (DSM-V; American Psychiatric Association [APA], 2013). These difficulties are present irrespective of language and intellectual ability (National Research Council, 2001).

Autism is also a condition marked by several memory-related difficulties, such as working memory and episodic memory (see Boucher et al., 2012; Griffin et al., 2021; Habib et al., 2019; Wang et al., 2017). Together, considering the diagnostic features of the condition (e.g., difficulties in social communication), autism is one possible condition to explore the idea of developing and testing a low language demand test of episodic memory. This measure has value for understanding the development of EM and neurodiversity in that development. The following section discusses the memory profile in autism together with the disadvantages of only using a conceptualist theoretical framework to assess and characterise EM in autism without a broader consideration of the social communication difficulties required for an autism diagnosis.

1.4 Autism Spectrum Disorder

1.4.1 What defines Autism?

Autism is a lifelong neurodevelopmental condition appearing early in development. Two clusters of autistic characteristics reflecting difficulties in social and non-social domains form an autism diagnosis. The first of these clusters are persistent deficits in three areas of social communication and interaction across numerous contexts (i) social reciprocity, (ii) nonverbal communication, and (iii) establishing and maintaining relationships (DSM-V; American Psychiatric Association [APA], 2013). The second of these clusters covers four types of behaviours. To receive a diagnosis, at least two out of these four behaviours must be present (in addition to social communication and interaction deficits). These restrictive, repetitive patterns of behaviours, interests, or activities (RRBIs), which are present to variable degrees, refer to (i) stereotyped or repetitive motor movements, (ii) insistence on sameness, (iii) highly restricted, fixated interests, and (iv) hyper-or hyporeactivity to sensory input or unusual interest in sensory aspects of the environment. Sensory issues may function across all the senses, including sound, taste, touch, or smell. Autistic people may be hypersensitive (over-responsive to certain stimuli such as bright lights, loud noise, and visual clutter and need to avoid such input) or hyposensitive (under-responsive to certain stimuli and require additional input). To capture the individual levels of support an autistic individual may need, those that meet the criteria for autism are also assigned a level of support: level 1 (requiring support), level 2 (requiring substantial support), and level 3 (requiring very substantial support).

Beyond marked difficulties in social communication and RRBIs, intellectual and language ability can vary widely in autistic individuals. For example, language onset may be delayed, lagging behind developmental milestones set for typical development, or absent altogether and may present with or without intellectual disability (meaning an IQ under 70). However, communication delays are prevalent in autism (Tager-Flusberg et al., 2005; Tager-Flusberg & Joseph, 2005).

Autism may also co-occur with other diagnoses, including genetic conditions (e.g., Fragile X syndrome), psychiatric disorders (e.g., Attention Deficit Hyperactivity Disorder [ADHD] (APA, 2013)) and mental disorders (e.g., anxiety [Gillott et al., 2001]; depression [see Stewart et al., 2006]).

Though autism is rooted in genetic factors, a lack of genetic markers for the condition means diagnosis involves standardised assessment tools that involve observational assessments and interviews (e.g., Autism Diagnostic Interview-Revised [ADI-R]: Lord et al., 1994; Autism Diagnostic Observation Schedule – Generic [ADOS-G]: Lord et al., 2000) across different settings (e.g., home, school, clinic). At present, a diagnosis typically ranges from 2.7 to 7.2 years, though a diagnosis is rare before three years of age. A diagnosis typically occurs earlier if autism occurs with social communication delays or intellectual disability (Loubersac et al., 2021).

Autism is the most common developmental condition, with prevalence figures for autism rapidly increasing over recent decades. Elsabbagh et al. (2012) suggest that one in 160 children has a diagnosis of autism (Elsabbagh et al., 2012). While more recent studies report substantially higher estimates that one child out of 145 has an autism diagnosis (Myers et al., 2019). As such, autism is the most common developmental condition, with epidemiological studies also showing a gender disparity of 3:1 more males receiving a diagnosis than females (Loomes et al., 2017). There is a great deal of discussion about why there is a gender imbalance, with a developing view that women and girls are underdiagnosed (Gould, 2017).

Several factors highlighting reasons for underdiagnosis include: females are more prone to ‘masking’ or camouflaging their autistic symptoms (Cook et al., 2017; Dean et al., 2017), alongside missed-diagnosis of females based on traditional diagnostic tools, which may not capture the way autism manifests in females (Rynkiewicz et al., 2016).

Together, the clinical picture that emerges of autism is one of vast complexity and variability, manifesting in multiple ways, resulting in a constellation of neurodivergent persons with specific strengths and needs requiring varying support levels (Bottema-Beutel et al., 2021).

1.5 Cognitive Theories of Autism

Various cognitive accounts propose to explain autism (e.g., mind-blindness, poor executive function, and weak central coherence). We will briefly consider the most prominent ones here as an in-depth review is beyond this thesis's scope (for review, see Happé, 1994). Though these theories have been influential in affording a deeper understanding of how autistic individuals may experience the world, unsurprisingly, none so far have offered a comprehensive characterisation of the condition due to its diversity (Happé et al., 2006). Nonetheless, cognitive theories explain, in part at least, the core diagnostic features of autism and also relate to the pattern of memory functioning in autism.

1.5.1 Theory of Mind Deficit – “Mind-blindness.”

Theory of mind (ToM), a domain-specific hypothesis of autism, first articulated by Premack and Woodruff (1978), is a subcomponent of social cognition. It facilitates social communications and interactions with others because it involves understanding other minds - the ability to put ourselves “in their shoes”. It is assessed using false-belief tasks where one needs to infer that another person does not possess the knowledge that they possess—

identifying that another person may have a false belief requires mentalising (Baron-Cohen et al., 1985), which requires meta-representation abilities (Perner, 1991; Perner & Roessler, 2012). Perner describes meta-representation as the ability to have a representation of a representation *as a representation* (Perner 1991, 2012). In terms of ToM, this means comparing and contrasting the two representations for inconsistencies by differentiating between one's knowledge and the other person's absence of it (e.g., what I know versus what someone else believes).

Similarly, EM shares the metarepresentational format implicated in ToM. Remembering is an active, ongoing reconstruction and recombination of the episodic details (Friedman, 1993) that involves re-experiencing experienced events (Perner, 1991; Perner et al., 2007). For example, Perner (1991) argues that to re-experience an experience (and understand that it is simply a representation of the actual event), one must be able to do two things; represent the event which requires meta-representational abilities attributed to ToM capacity, and relate the self as the experiencer of the memory across subjective time; hence the relationship between ToM and EM has been construed as interdependent, both sharing the same conceptual abilities and occurring at approximately the same point in development at 4-years of age (Perner, 2001; Perner et al., 2007; Perner & Ruffman, 1995).

It follows, then, that Autistic individuals should have difficulty in episodically recollecting events because it involves the meta-representation of an experience in the same way as understanding another individual's mental state. But as the next section will consider, this only constitutes one aspect of the cognitive challenges autistic individuals face.

1.5.2. Poor Executive Function

An alternative to the ToM account that has garnered attention is the executive dysfunction account of autism. This account posits a broad, domain-general deficit underpinning social and non-social issues. Unlike the ToM account, this account proposes that autism is a secondary consequence of the downstream effects of executive function difficulties. Executive functions (EF) are an umbrella term for the top-down cognitive processes that underpin a person's ability to accomplish daily tasks and navigate social interactions in everyday life. There is considerable evidence to suggest that autistic people have significant executive function difficulties (Hill, 2004), which we will discuss in turn.

EFs commonly fractionate into three subdomains; working memory, inhibition, and shifting (Miyake et al., 2000). Baddeley (1992, p. 556) defines working memory as the "temporary storage and manipulation of the information necessary for such complex cognitive tasks as language comprehension, learning, and reasoning". This finite store, limited in duration and capacity, allows one to retain and dynamically update information in temporary short-term memory (Baddeley, 2012).

Inhibition is necessary for complex goal-directed behaviour (i.e., being able to exert self-control) to inhibit a previously learned or prepotent response or to resist distractors – enabling one to focus on the task at hand without being distracted by perceptual cues. Finally, cognitive flexibility/shifting refers to the capacity to switch between mental processes in response to changing demands (Dajani & Uddin, 2015), including seeing from a different perspective and adapting accordingly). Collectively, these functions enable a person to direct and disengage their attention in the immediate environment to guide their actions (Hill, 2004).

Therefore, difficulties in EF can have significant implications for various outcomes such as social functioning (Brock et al., 2009; Shaul & Schwartz, 2014), problem-solving and rigid, perseverative behaviour (Steel et al., 1984), and reasoning (Diamond, 2013).

In social situations, EFs enable us to focus and shift between topics and turn-taking in conversations (Faja et al., 2016). Findings link many autistic characteristics to executive functioning difficulties, such as restrictive, repetitive behaviours (Lopez et al., 2005), cognitive flexibility (Reed et al., 2013) and social functioning (Brock et al., 2009; Shaul & Schwartz, 2014; but see Baron-Cohen et al., 1999; Griffith et al., 1999; Hill & Russell, 2002; Russell & Hill, 2001).

EFs, in particular, working memory, play a pivotal role in the storage and recovery of episodic memories (Meléndez et al., 2019). Episodic recall is not an identical replay of the actual event (Rosenfield, 1988; Suddendorf et al., 2009). Instead, it is a conscious act of reconstructing and recombining the episodic details (Friedman, 1993). For instance, WM underpins the transfer and the stabilisation of memories into long-term storage. Therefore, difficulties in WM may impact the storage, maintenance, and retrieval of past episodes (e.g., Ricarte et al., 2016) because they enable one to verify the memories while also managing to inhibit irrelevant information (Baddeley, 2012). As such, difficulties in these aspects of executive functioning are relevant for episodic memory. There is a wealth of information that, whilst not clear cut, suggests that executive functions are compromised in autism and may be implicated in the difficulties experienced in EM (e.g., Crane et al., 2013; for review see, Craig et al., 2016).

1.5.3 Weak Central Coherence

Finally, Weak Central Coherence (WCC) theory accounts for the non-social deficits in autism unexplained by ToM (Frith & Happé, 1994). Coherence refers to the tendency to integrate context and gist to establish higher-level meaning at the expense of individual details/patterns of information (Frith, 2003). Following the observation that autistic individuals attended preferentially to details resulting in difficulties in using context for global meaning, the 'weak central coherence' account was developed, referred to as 'not seeing the forest for the trees' (Frith, 2003). This was noted as far back as in Kanner (1943), where he stated that there was an “inability to experience wholes without full attention to the constituent parts…” (Kanner, 1943, p. 246).

Evidence for this account has been demonstrated using a variety of simple, perceptual tasks like the block design tasks (Shah & Frith, 1993) and embedded figures tasks (Edgin & Pennington, 2005; Jolliffe & Baron-Cohen, 1997; Shah & Frith, 1983; Jolliffe & Baron-Cohen, 2001). Autistic individuals outperform their neurotypical counterparts demonstrating superior performance in these tasks because they are more successful at picking out details from a distracting background, suggesting less global interference (see review Dakin & Frith, 2005). It differs markedly from the ToM and EF accounts of autism, which propose primary deficits. This posits a cognitive style (Happé, 1999), one of ‘enhanced local processing’ (Mottron et al., 2006; Mottron & Burack, 2001), emphasising strengths in autism rather than weaknesses.

Though an ‘enhanced local processing’ bias explains the non-social domain (restricted, repetitive, routinised behaviour resulting from this overarching tendency towards attending to and processing precise details and becoming distressed over minor changes), processing information in context is relevant to EM.

EM requires representing a coherent and bound memory from the past recursively. Thus, focusing on details specific to an event rather than context would predict the tendency to perform poorly on source memory tasks (recalling the source of memory) because the information is piecemeal. For example, Loth et al. (2008a) have suggested that details not central to the event are recalled more easily than global elements because they are irrespective of the context (Loth et al., 2008). McCrory, Henry, and Happe (2007) also found that in autism, a lack of central coherence results in a greater reliance on more generic cognitive resources during recall.

1.5.4 Summary

The cognitive theories outlined above help add to our understanding of the strengths and challenges of autism. While none of these theoretical positions can account for the complete cognitive, social and non-social profile in autism, they aid our understanding and help identify areas of strength/disablement associated with autism when considering the memory profile in autism: (1) ToM – and the metarepresentation abilities that are critical for EM - and may be missing in younger children; (2) Executive functions, in particular, working memory in the reconstruction and recombination required when recalling memories; and (3) a cognitive style towards enhanced perceptual processing resulting in difficulties in recalling the contextual information that defines a gestalt memory.

1.6 Memory in Autism

The memory profile in autism has been under study for decades. Despite not forming part of the diagnostic criteria, autism presents with a distinct pattern of strengths and difficulties in memory functioning not accounted for by the varying degree of language or intellectual disability or co-occurring conditions that may accompany the core diagnostic features (see Figure 1.4). Therefore, we begin this section with an overview of these memory difficulties, their theoretical underpinnings, and methodological considerations that have implications for the current directions of this thesis.

1.6.1 Episodic memory in Autism

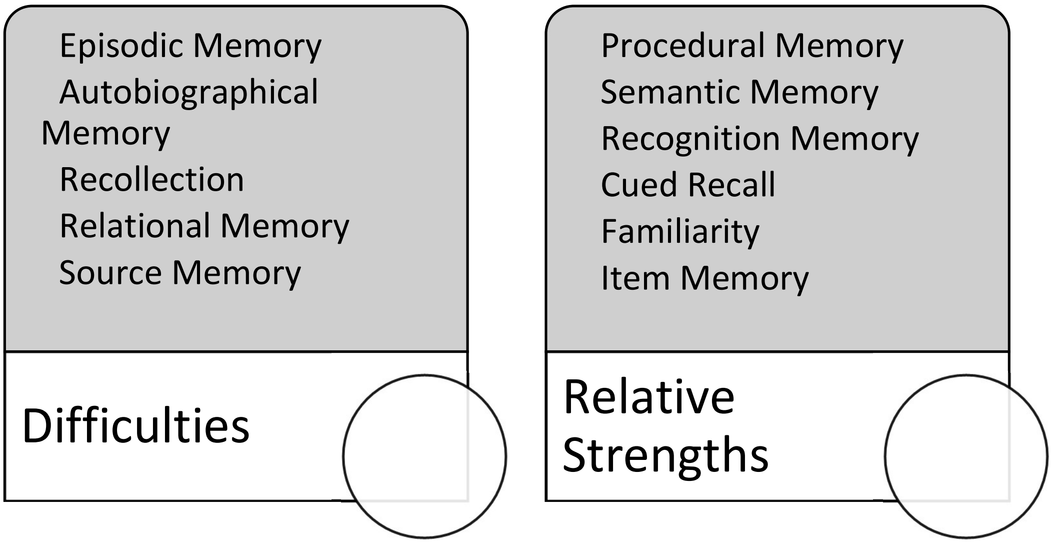
As mentioned at the beginning of this chapter, episodic memory is part of the declarative memory system that encodes, stores, and allows access to episodic memories. EM is associated with autonoetic consciousness (Tulving, 2001), an awareness characterised by ‘remembering’ by mentally travelling back in time to re-experience the initial event. Though semantic and episodic memory is inextricably intertwined, they are functionally distinct (Renoult et al., 2019).

In autism, a sizeable body of evidence lends support to the idea that episodic memory is disproportionally affected compared to semantic, implicit, and familiarity-based memory (for reviews, see Boucher, 2012; Cooper & Simons, 2019b; Desaunay et al., 2020 [meta-analysis]; Lind, 2010; Mottron et al., 2001; Shalom, 2003). Autistic individuals often recall fewer or less specific memories of previous encounters (Maister et al., 2013). They also recall with less detail and elaboration and are slower to recall them when asked about their past (e.g., Bruck et al., 2007; Crane & Maras, 2018; Gaigg & Bowler, 2018; Goddard et al., 2007).

Several facets of memory contribute to these difficulties, which we will consider when discussing the evidence: (1) recollecting personally experienced events (e.g., Crane et al., 2009; Goddard et al., 2007; Klein et al., 1999; Millward et al., 2000), (2) relational processing (e.g., Bowler et al., 2000, 2007; Gaigg et al., 2008; Lind & Bowler, 2008; Toichi, 2008), and (3) source monitoring (e.g., Bowler et al., 2004). Moreover, these difficulties appear to be related to retrieval mechanisms rather than issues with incomplete encoding, both of which depend on several factors (Cooper et al., 2017; Cooper & Simons, 2019).

The methodological approach from which these conclusions are drawn broadly originates from studies assessing EM processes using (1) autobiographical interviews/traditional laboratory-based EM assessments using free recall; (2) Remember/Know judgments in recognition memory (conscious awareness of retrieval processes), and (3) source-memory tasks (i.e., memory for the context of item presentation (see Maras & Bowler, 2012). The various studies that report autism-related difficulties in episodic memory also overlap on a central feature. They conceptualise EM in terms of its unique phenomenology employed in the act of recollection (i.e., being autonoetically aware). This act of remembrance means placing yourself back in the past (i.e., mental time travel) to subjectively recollect and integrate all the details from the past event into a conscious first-person experience. This rich conceptual capacity allows the person to give an elaborative account of memory's contextual and event-specific features, such as what-where-when and with whom an event occurred, even when that memory is physically dissociated from the person’s current environment.

Figure 1.4 *The pattern of Memory Functioning in Autism*



Note. The image shows the pattern of strengths and relative difficulties in memory functioning in autism.

1.7 Factors influencing episodic memory in Autism

1.7.1 Recollecting personally experienced events

As mentioned at the beginning of this chapter Tulving (2002) proposed that the concepts of self (across subjective time) and autonoetic awareness together form the essence of episodic memory.

1.7.2 Memory with the S*elf* in the centre

There is accumulating evidence suggesting specific difficulties in retrieving memories relating to the self in autism (e.g., Crane et al., 2009; Goddard et al., 2007; Klein et al., 1999; Millward et al., 2000) with autistic individuals finding it difficult to distinguish between themselves and others as the executor of an action. For example, Millward et al. (2000) compared memory for events performed by the self and peers. The task involved walking to specific locations and carrying out certain activities (e.g., visiting horses in a sanctuary) conducted by the self or an accompanying peer. Millward et al. (2000) found that Autistic children (ages 5–6) matched for language ability recalled significantly fewer event details when they had to recall their own activities than observed events performed by a peer. The opposite pattern occurs for IQ-matched non-autistic children and CA-matched intellectually disabled children (i.e., self-enactment effect - better memory for actions carried out by the self versus others). Wojcik et al. (2011) also failed to find significant enactment effects among autistic children. There is also evidence to suggest a reduced self-reference effect. Grisdale et al. (2014) found that while non-autistic peers recalled information belonging to the 'self' better than those belonging to another person, autistic individuals did not differentiate between self vs other-referent items recalling both equally well. Research suggests autistic individuals are less likely to retrieve information from a first-person perspective (Lind et al., 2014; Lind & Bowler, 2010).

The resultant picture suggests autism-specific difficulties in recalling *personally* experienced past events related to the self. However, subsequent research has not consistently identified differences in the ability of autistic individuals to recollect whether they or someone else acted (Farrant et al., 1998; Grainger et al., 2014; Hill & Russell, 2002; Lind & Bowler, 2009; Williams & Happé, 2009; Zalla et al., 2010). Furthermore, a typical enactment effect (better memory for self versus others) is observed on tasks that require fewer social demands (Grainger et al., 2014; Williams & Happé, 2009). For example, Grainger et al.

(2014) examined action monitoring using an online squares task. In the study, autistic individuals had to detect which square was controlled (using a computer mouse) by their own actions (versus another person: movements influenced by the experimenter, but the participant's hand was always on the mouse). In addition, participants were asked to identify which square (out of several distractor squares) on a computer screen was directly controlled by the participant as opposed to the experimenter. The authors reasoned that if accurately monitoring their own actions is a veridical issue in autism, it should not matter who controls the mouse; they cannot rely on the experience of agency to perform the task. Given that autistic individuals showed no evidence of action monitoring impairments and demonstrated typical enactment effects (better memory for self-performed actions), the authors concluded that awareness of the physical self is relatively unimpaired. This supports the view that action monitoring (and physical self-awareness, more generally) is undiminished in autism.

Studies on metamemory in autism suggest that, despite autistic individuals being aware of their memory functioning, they have difficulty mentally reinstating the self into the past to recall a specific incident (Wojcik et al., 2013). One aspect of metamemory is the feeling-of-knowing (FOK), in which participants are asked to predict the likelihood of correctly recognising items that are currently not-recalled. It focuses on what is and what is not remembered or known. Wojcik et al. (2013) examined metamemory performance in autistic individuals by investigating what they know about their memory performance rather than what they retrieve from memory. They administered two parallel tasks to assess metamemory functioning using semantic and episodic information using the feeling-of-knowing (FOK) paradigm. First, word pairs (cue-target pairs) were evaluated using a cueing paradigm in the episodic task. Where participants were unable to recall the corresponding item when shown a cue word, they were asked to make a FOK prediction by saying whether or not they would be able to recognise the correct word if it was presented amongst other words. To explore semantic FOK, judgments are made about information already stored in memory—general knowledge (verbally defining words from the Peabody Picture Vocabulary Test). Results showed that autistic children made more inaccurate FOK predictions for episodic materials than those made for general knowledge (semantic), pointing to a specific difficulty in recollection associated with retrieving the relevant contextual information, which relies on mentally returning to the experience to retrieve the contextual details for the study episode.

Findings of reduced episodic memory (yet preserved semantic memory) have also been drawn from studies using the Remember/Know procedure. The logic behind the remember/know task is to classify one's awareness when reflecting on a memory. While both episodic and semantic memory is consciously accessible, when the qualitative information associated with the past event is accessed by re-experiencing the initial event, the memories are defined as ‘remembered’ and, thus, episodic because they are tightly accessed and associated with autonoetic awareness. Whereas memories that are ‘known’ transpire without a feeling of re-experiencing and involve a noetic awareness. Several studies investigating these phenomenological distinctions using the R/K recognition procedure have found that autistic adults report less “remembering” and more “knowing” than in typical IQ-matched comparison groups, even when overall recognition memory is unaffected (Bowler et al., 2000). This is because remembering reflects autonoetic consciousness – requiring an awareness of the self situated in subjective time, allowing the shift from the present to the past to enable the event to be re-experienced. This would suggest that EM in autism is essentially compromised because of the reduced ability to take on a different perspective, whether in time or space, to reinstate contextualised events permitting a richer recollective experience.

Tanweer et al. (2010) combined autobiographical memory tasks with an R/K procedure and found a greater reliance on noetic than autonoetic awareness in autistic adults.

When autonoetically aware, an individual is reflectively conscious that the self exists in the past, present, and future (Vandekerckhove & Panksepp, 2009). This suggests that the subjective experience of episodic remembering is qualitatively different in autistic adults (but see Bowler et al., 2007). Bowler et al. (2007) investigated several factors affecting remember and know responses (e.g., allocating conscious processing resources – divided versus full attention, perceptual manipulations of study and test modality, and susceptibility to the false recognition effect). They found that autistic adults and non-autistic comparison groups demonstrated a similar reduction in 'remember' judgements under divided attention conditions than for 'know' responses. Also, when visually/ auditorily studied words are then tested for recognition in a different modality, autistic adults and non-autistic comparison groups respond similarly by attenuating their know responses but not remembering judgements. Lastly, when words closely associated with a nonstudied word were given greater exposure, they found this increased remember responses in autistics and non-autistics. The findings demonstrate that although remembering is quantitatively different in autism, the information and the experience are qualitatively similar to that experienced by non-autistics.

1.7.3 Relational processing

For an episode to be retrieved, its components need to be marked to retrieve it in a bound unit. Thus, one of the explanations for why autistic individuals experience disproportionate difficulties on tests of free recall (but are comparable to non-autistic peers on cued-recall or recognition tasks) relates to relational processing difficulties during encoding - the relational binding hypothesis (see Bowler et al., 2011; Bowler & Gaigg, 2008 for reviews). The hypothesis suggests that the diminished capacity in EM in autism derives from a hippocampal-related difficulties in relational memory, while brain mechanisms mediating item-specific or simple item-item associations remain unaffected. The hypothesis assumes that the relational information about item-specific or item-item information can only be related if relations between items are encoded (Gaigg & Bowler, 2013; Hunt & Einstein, 1981). Gaigg et al.(2008) examined item-specific and relational encoding in autistic adults. In the task, participants studied lists of words printed on cards that included varying instances of items belonging to different categories (for example, 56 words comprising 2 Items of Fruit, 4 Professions, 8 Countries, 12 Animals, 16 Furniture). The task included three conditions: a baseline and two orienting tasks, relational and item-specific. In the baseline, task participants were presented with words from a set of categories (e.g., Sports, Clothing, Weapons, Countries and Animals) and simply asked to remember as many words as possible. The rationale was that items from smaller categories would have less relational information available to aid recall which would be particularly evident in the baseline condition rather than the orienting tasks, which involved task support.

On the other hand, larger categories have more word clustering, allowing more opportunities to aid recall. For the orienting tasks (which provide task support), participants needed to sort the word cards into their relational categories in the relational condition. Participants were asked to rate each word on a 5-point pleasantness rating scale (very pleasant, a little pleasant, neutral, and a little unpleasant. Following this, participants were asked to recall freely as many words as possible. Results showed that autistic individuals exhibited a spontaneous recall decrement in the baseline condition, particularly recalling fewer words from the smaller categories than non-autistic peers. This was not the case for the relational orienting task, which suggested that specific difficulties in relational memory can be attenuated by providing procedural support – *Task Support Hypothesis* (Bowler et al., 2004; Bowler et al., 1997) and because of this might in principle be unaffected in autism (Gaigg et al., 2008) because it is open to adequate support (see Bowler & Gaigg, 2008). However, subsequent research using behavioural and eye-movement data suggests that a relational binding deficit may not be the sole cause of episodic recollection difficulties in autism (Cooper et al., 2015; Ring et al., 2016).

1.7.4 Source monitoring

Another important recurrent finding contributing to our understanding of memory in autism is source monitoring; this means understanding the memory source (Johnson et al., 1993). This can be knowing how you know something (source monitoring) or when or where it was learned (e.g., spatial, temporal, perceptual) and extends beyond recognition memory (Johnson et al., 1993). Because autonoetic awareness is tied to a particular spatial and temporal context, a prerequisite for successful source monitoring is remembering because it is needed to retrieve the contextual information (Johnson et al., 1993). Source identification relies on the quality of information encoded about an event when it occurred and on *reactivating* the initial event to discern the source of the memory (Johnson et al., 1993).

In such tasks, autistic individuals reliably exhibit difficulties in identifying the correct knowledge source (e.g., Bowler et al., 2004; Lind & Bowler, 2009), but recognition memory (old/new items) remains undiminished. For example, 4-6-year-old autistic children showed recall for facts. Still, after five years of age, they lag behind their non-autistic counterparts when identifying the correct knowledge source – here, this was recalling the temporal context ('yesterday') . Bowler et al. (2015) investigated the role of task support on temporal and spatial source memory using a recognition paradigm. In the experiment, autistic adults were asked to study 3 different lists of words explicitly labelled as 1st, 2nd, and 3rd list—each word list comprised of 9 words, which were presented sequentially in random order. Then, following a 5-minute delay, a recognition test was performed in which autistic adults had to identify words from the list as previously having seen in a left-right organisation on-screen (spatial judgement) or the first, second or third list (temporal judgement). The authors found that their recall of difficulties in temporal source memory persisted even when explicit temporal cues were given; this was not the case for recognition with the aid of spatial cues.

Thus, the notion that performance on source memory can be improved with appropriate task support does not seem to be the case for temporal source judgements (Bowler et al., 2015).

1.7.5 Summary of Memory in Autism

The difficulties in Episodic Memory in autism were theorised to result from problems in encoding, given that adequate support at retrieval improves performance for autistic people (but see Boucher et al., 2012; Cooper et al., 2017). Subsequent research dissociating encoding and retrieval processes found a distinct difficulty in retrieval processes; the ability to consciously monitor and reconstruct past events (for a review, see Cooper & Simons, 2019). This finding is paralleled in fMRI research which found reduced hippocampal-cortical connectivity for the recollective experience during retrieval in autism (for review, see Cooper & Simons, 2019). Moreover, episodic memory difficulties are attenuated when cognitive control and retrieval demands are minimised (Bowler et al., 2004; Crane et al., 2013; Maras et al., 2013; Solomon et al., 2016). Together, such research provides important insights into the episodic abilities of autistic adults. However, it also highlights that it is relevant to understand EM in autistic children, particularly across the full autism spectrum.

1.7.6 Methodological considerations:

The methodological approach from which these conclusions are drawn broadly originates from studies assessing EM processes using (1) autobiographical interviews/traditional laboratory-based EM assessments using free recall; (2) Remember/Know judgments in recognition memory (conscious awareness of retrieval processes), and (3) source-memory tasks (i.e., memory for the context of item presentation (see Maras & Bowler, 2012) with noted exceptions (Cooper, Plaisted-Grant, et al., 2017; Ring et al., 2016; for review see Cooper & Simons, 2019). Together these reveal differences in the number of memory details recalled, the richness of the reported phenomenological information and the subjective experience accompanying retrieval in autism.

The various studies that report autism-related difficulties in episodic memory overlap on a central feature. They conceptualise EM in terms of its unique phenomenology employed in the act of recollection (i.e., being autonoetically aware). This act of remembrance means placing yourself back in the past (i.e., mental time travel) to subjectively recollect the original experience from a first-person perspective. This rich conceptual capacity allows the person to give an elaborative account of memory's contextual and event-specific features, such as what-where-when and with whom an event occurred, even when that memory is physically dissociated from the person’s current environment.

One obvious problem with free recall techniques, whether they involve word lists/sentences or an experienced event, is that they are verbal-centric, requiring reciprocity and verbal exchanges between the experimenter and the participant. This may be problematic for autistic individuals, who have social communication difficulties by definition of their diagnosis (American Psychiatric Association, 2013) and difficulties in autonoetic consciousness (for review, see Lind, 2010). Furthermore, memory and language processing are closely intertwined (Duff & Piai, 2020); language is the device by which episodic memories are communicated (Corballis, 2019). Several studies have demonstrated a link between EM abilities and expressive language skills in autistic children (e.g., Boucher, 1981; Goddard et al., 2014) and difficulties in pragmatic language (e.g., social and communicative aspects of conversational interactions, narrative skills, social discourse) which are present regardless of language level or age (Baird & Norbury, 2016; Lam & Yeung, 2012; Lord et al., 2015; Volden et al., 2009; Wilkinson, 1998; Young et al., 2005). In autism, subtle weaknesses in language persist (in pragmatic and semantic language) even in those autistic individuals who no longer meet formal criteria. Kelley et al. (2006) found that autistic children (5-9 years) who no longer met a diagnosis perform similarly to non-autistics when it comes to grammatical abilities but that difficulties in pragmatic, semantic language remain (including narrative story production and mental state verb production [e.g., ‘think’ vs ‘guess’]). These weaknesses were no longer evident in a later study (8-14-year-olds) which included some of the children from the original research; narrative production was not (Kelley et al., 2010). Other studies have demonstrated selective dificulties in spatial language (such as remembering spatial terms from short stories (e.g., near and far or out of and down off) in autistic individuals (9-27 years) compared to non-autistic counterparts, matched on chronological age and cognitive abilities, were more difficult for autistic individuals (Bochynska et al., 2020). Thus, revealing difficulties in spatial language that can affect daily communication about objects’ locations and navigation (Bochynska et al., 2020). Goddard, Howlin, Dritschel, and Patel (2007) also found that when asked to generate memories of specific autobiographical events, autistic individuals take longer to do so. Norris and Maras (2021) found that expressive language ability predicts recall specificity of autobiographical information, which was not the case for non-autistic peers. Overall, relying on verbal-centric methods to assess episodic memory might further compound their memory recall difficulties by virtue of their diagnosis. Procedures based on verbal-centric interviews/laboratory-based free recall tasks might obscure the precise nature of the challenges in EM, which may not be reflected in their performance; weaknesses may, at least in part, reflect the methodological procedures used. There is a clear need to use a measure with minimal narrative demands.

Consistent with this observation in non-autistic children, studies using minimally verbal content-based tasks of EM have reliably found that younger children’s episodic abilities are underestimated (e.g., Hayne & Imuta, 2011). This finding indirectly underscores that emphasis should not always be placed on speech to communicate personal experiences. Instead, such information should be imparted through other nonverbal mediums. Thus, while the quantitative aspects of episodic retrieval are implicated as significant in autism, the qualitative element tends to be similar. This highlights that even though it is uncontroversial that diminished episodic skills are present in autism, the memory profile is complicated because autism is, by definition a condition with significant difficulties in social communication irrespective of intellectual and language ability.

Studies using autobiographic interviews often report significant difficulties in retrieving memories in autistic children (Bruck et al., 2007; Maister et al., 2013), evidenced by recalling fewer event-specific details concerning their autobiographical memories (i.e., memory for past experiences of the self). These difficulties are present whether autistic individuals are matched to children of comparable age and intelligence (IQ) (Bruck, London, Landa, & Goodman, 2007) or those with verbal and non-verbal abilities differing only in age (Mattison et al., 2018; Mattison et al., 2015) or whether they have accounted for differences in narrative skills (Ciaramelli et al., 2018). Together these indicate a selective difficulties of the episodic memory system in autism.

However, we also know that the methods and techniques used to probe episodic abilities within autobiographical interviews can substantially affect the amount and accuracy of the information provided (Almeida et al., 2019; Maras & Bowler, 2010). This is beyond known differences in using broad, open-ended prompts used in free recall compared with cued recall, typically comparable with matched non-autistic counterparts (Bennetto et al., 1996; Minshew & Goldstein, 1993). For example, accuracy was compromised for autistic individuals when free recall involved changing the order of recall (in reverse order) and mentally reinstating the physical (external) and internal (subjective) context before recalling the real-life reconstruction of an event (Maras & Bowler, 2010). In contrast, without these mnemonic strategies (which paradoxically aimed to elicit more detailed and accurate descriptions), autistic individuals performed equally to controls regarding the quality and quantity of the information provided. This finding indicates that how we assess episodic memory profoundly affects the outcome and our understanding of the memory profile in autism.

Nonetheless, the fact that the memory difficulties recalling events also parallel findings from studies requiring the free recall of sentences and word lists suggests that, at least in part, there are core difficulties in EM. Specifically, evidence suggests difficulty in retrieving word lists/sentences composed of semantically related words (Bowler, 2001; Bowler et al., 1997; Salmond et al., 2005) but not unrelated words (Ambery et al., 2006; Bowler et al., 1997, 2008; Williams et al., 2006), suggesting difficulties in memory integration and associative processes.

However, while autistic children may provide fewer details overall than non-autistic children, they often accurately memorise the event details performing similarly to their non-autistic counterparts. Thus, underscoring that while the objective features may be correct, the subjective phenomenology allowing us to reflect on the content of our memories may be compromised.

1.8 Alternative approach to studying EM in Autism

An alternative approach to studying episodic memory developed from studies examining episodic-like memory in animal cognition. This approach adopts a nonverbal paradigm and assesses the behavioural content of episodic memory; what happened, where it happened and when/which occasion the event occurred. Importantly, it does not include the subjective phenomena accompanying episodic memory as Tulving (2002; 2005) described. Nevertheless, despite omitting the experiential component, there is convincing evidence to suggest a relationship between recollection-based retrieval processes and episodic-like memory tasks. For example, non-autistic adults were more likely to associate their WWW memories (Holland & Smulders, 2011) and WWWhich occasion memories (Easton et al., 2012) with the experience of “remembering” rather than the feeling of “knowing”.

As such, given autism-related difficulties in relational-binding and autonoetic consciousness, it is surprising that WWWhich/WWWhen tasks have received no attention. There has been no previous experimental investigation of EM in autism using a behavioural content-based WWWhen or Which occasion to the best of our knowledge. This is an ideal behavioural task to investigate EM in autism, considering the definitions that have been imposed upon EM. Notably, the WWWhich task can shed light on the relational binding issues documented in autism. For example, as highlighted in previous sections, content-based tasks examine specific episodic recollection components. In addition, it will allow us to compare the individual associations of What-Where, What-Which, and full episodic binding (what-where-which occasion). Thus, different binding levels can give insight into the relational binding difficulties in autism.

Episodic-like memory tasks also do not require an explicit verbal response. As such, it would overcome the language and autonoetic demands commonly associated with traditional episodic memory tasks, thereby facilitating recall about a personally experienced event. In addition, this allows us to standardise the level of language complexity across different age groups. Lastly, this paradigm has the translational potential of being used with young, old, non-autistic, and neurodivergent groups.

1.9 Aims of thesis

The aims of this thesis are exploratory – we aim to develop an episodic memory task that adopts a nonverbal and content-based approach to assess what-where-which episodic memory (and its binding components), which can be used with typically developing children across a wide range of ages (3-11 years) and autistic children. The difficulty level is somewhat standardised by removing the need for explicit communication. It broadens the scope of its applicability for use with autistic individuals with limited language or intellectual abilities. Autistic children's episodic memory problems are also less evident under conditions where narration demands are lower (Lai et al., 2017 for reviews). To achieve these aims, this thesis includes three studies, each testing non-autistic adults (Experiment 1), non-autistic children between 3 and 11 years (Experiment 2) and autistic children (6-11 years) (Experiment 3) using a WWWhich content-based task. The WWWhich content-based task examined the integration and binding of the what-where-which criteria allowing us to isolate binding for what-where and what-which and whether these predict outcomes in terms of other domain-general skills (e.g., visuospatial working memory, visual short-term memory). Its delivery and execution were minimally verbal in terms of adults and non-verbal for non-autistic and autistic children to reduce social communication demands.

Experiment 1 aimed to develop a nonverbal and content-based approach to assess what-where-which episodic memory (and its binding components) that can be used with typically developing children across a wide range of ages (3-11 years) and autistic children and is transportable across sites. This would allow a comparison of EM across different age groups, populations and testing sites using a modified version of the WWW task from Holland and Smulders (2011) and the WWWhich task by Eacott and Norman (2004). Thus, using a controlled (yet naturalistic) protocol to examine what-where-which episodic memory contributes a new paradigm to the existing literature, advancing experimental design skills.

Experiment 2 – following the development and refinement of the methodology in Experiment 1, this study served as a connection and extension to previous studies that have used content-based memory tasks to investigate EM in non-autistic children. Specifically, previous studies using content-based tasks in typically developing children mainly adopt a verbal approach despite being behavioural in content.

Experiment 3: Having established that autistic individuals present a characteristic profile in memory. Previous studies have predominantly used verbal recall methods, and autism is defined by social communication difficulties as well as particular challenges in the language domain (e.g., Howlin & Asgharian, 1999; Loucas et al., 2008; Tager-Flusberg et al., 2005; Tager-Flusberg & Joseph, 2003), it would be informative to generalise these findings using non-verbal techniques where autistic children can show, rather than tell us the contents of their memory. Fundamental differences in episodic memory skills in autism should persist in behavioural tasks that are non-verbal.

2 Establishing EM Paradigm using Adults

This chapter outlines aspects of the methodology and procedure used during all experiments. It explains how the methodology used throughout this thesis was designed and refined based on episodic-like memory paradigms such as What-Where-When (Holland & Smulders, 2011) and What-Where-Which occasion (Easton et al., 2012). Episodic-like paradigms consist of multiple components that define the content of a memory rather than its experience, which is extremely difficult to assess without language. We used an iterative process in developing this paradigm with an emphasis on making it neurodevelopmentally appropriate and non-verbally mediated for future use with neurotypical children of a wide range of ages and autistic children. The current chapter focuses on identifying the evidence for the usefulness of adopting a behavioural and non-verbal approach to episodic memory assessment, the neurodevelopmental considerations adopted in developing the paradigm and testing the feasibility of the methodology on individuals with a mature episodic memory system, namely adult humans.

2.1 Introduction

Episodic memory is typically measured using abstract, verbally-mediated tasks such as free-recall assessment methods (e.g., recounting experiences or lists of words). For several reasons, such methods may be inherently compromised for use in neurodevelopmental conditions such as Autism Spectrum Conditions. First, social communication barriers are sufficient to impact the autistic individual's social interactions in everyday life. Hence, warranting a diagnosis. Second, language plays a fundamental role in facilitating the expression of conscious recollection. As a result, much of what we know about episodic memory in autism derives from adult-centric studies involving autistic participants without language or intellectual disabilities. Consequently, the use of verbally mediated tasks limits the extent to which we can unravel challenges in communication from episodic abilities and obscures our understanding of the universal nature of any difficulties in episodic skills across the autistic spectrum.

As described in Chapter 1, episodic memory has been conceptualised in three main ways; conceptualist, minimalist and Kantian approaches, which diverge in how they characterise episodic memory as having a distinctive phenomenology that involves 'mentally reliving' or 're-experiencing' a past event. This renders episodic memory challenging to assess in young children and neurodivergent groups where language, social communication, and introspective abilities may be a barrier to communicating the 'felt' qualities of their experiences.

Current estimates of autism prevalence suggest that around one in 57 (1.76%) children in the UK have a diagnosis of autism (Roman-Urrestarazu, 2021). As mentioned above, social communication difficulties are a diagnostic requirement for autism. One component of social communication involves pragmatic language, such as knowing how much information is relevant to include in discourse and maintaining the topic of conversation. There is substantial evidence that pragmatic language, as well as turn-taking, are impacted in autism (Adams, 2002; Adams et al., 2009; Volden, 2002; Volden et al., 2009).

While language difficulties have been removed from the DSM-5 (American Psychiatric Association [APA], 2013) as a diagnostic feature of autism, a significant proportion of autistic individuals experience difficulties with acquiring spoken language, with around 25-30% of autistic children remaining minimally verbal at school age (Anderson et al., 2007; Norrelgen et al., 2015; Rose et al., 2016). There is a significant body of evidence regarding communication abilities in autism, suggesting that among those autistic individuals that acquire spoken language, pragmatic language difficulties remain a universal feature (Paul & Norbury, 2012) and reveal significant memory limitations depending on the degree of language impairment, particularly in such tasks which require verbal responses, while those that are more visually based do not (Hill et al., 2015). Hill et al. (2015) found that the increased demands associated with a verbal working memory impact performance and differentiate between those with and without language impairment.

Due to the shortcomings listed above, the current study aimed to overcome barriers in language and communication by innovatively adapting minimalist content-based episodic-like memory paradigms such as the what-where-when [WWW] (e.g., Holland & Smulders, 2011) and the what-where-which occasion task [WWWhich], (e.g.,(Eacott & Gaffan, 2005; Eacott & Norman, 2004; Easton et al., 2012a; Newcombe et al., 2014a), to examine episodic memory in non-autistic and autistic children.

There were three primary areas to consider. First, EM content-based tasks such as the WWW and WWWhich, use content-based indices that break an episode into its parts (e.g., recall of what- happened [engaging conversation], where [on the train to London]) and when/which occasion (last Friday during my trip with Susan, it was raining). These individual elements (e.g., the sensory information, encoding context, and spatial components that make a unique event) weave together to form a coherent memory which can then be combined and recalled flexibly (Clayton, Bussey, & Dickinson, 2003). For example, "It was raining last Friday, and I was on the train with Susan travelling to London". This aligns with Tulving's original definition of episodic memory as one that "receives and stores information about temporally dated episodes or events, and temporal-spatial relations between them (Tulving, 1972). This means that content-based approaches demonstrate 'episodic-like memory in the absence of language because there is no requirement to provide conscious recollection (i.e., autonoesis) of the event, as Tulving (2002b, 2002a) described.

However, despite being behavioural in content, the examination of this content often is not, and assessments are verbally mediated – relying upon adults and children to use spoken language to communicate answers. Autistic children have a broad range of communication abilities: some students have an impressive vocabulary, while others may not have spoken language. Therefore, research must prioritise reducing dependence on spoken communication to relate the contents of memory by using nonverbal behaviour as an alternative – making it child-centred. This will allow the autistic child to interact and communicate with a broader audience within research.

Surprisingly, as outlined in Chapter 1, there is a paucity of research using WWW and WWWhich content-based EM models with neurodivergent groups. In fact, to the best of our knowledge, only one study using the WWW paradigm investigates episodic abilities in Williams syndrome (Mastrogiuseppe et al., 2019) and none with autism spectrum conditions. This raises the fundamental question of whether we can employ this particular paradigm in the autism population and what methodological challenges need considering. Likewise, the WWWhich task has not been used to assess memory in neurodevelopmental conditions but has in typical development (Newcombe et al., 2014).

Second, we wanted to combine the richness of real-life memories in which individuals interact with their environment in specific contexts and physical spaces with systematically controlled laboratory-based approaches. This allows for the controlled study of objective features in the free-retrieval of objects (What) located spatially in a physical space (Where) within a visual context (Which context).

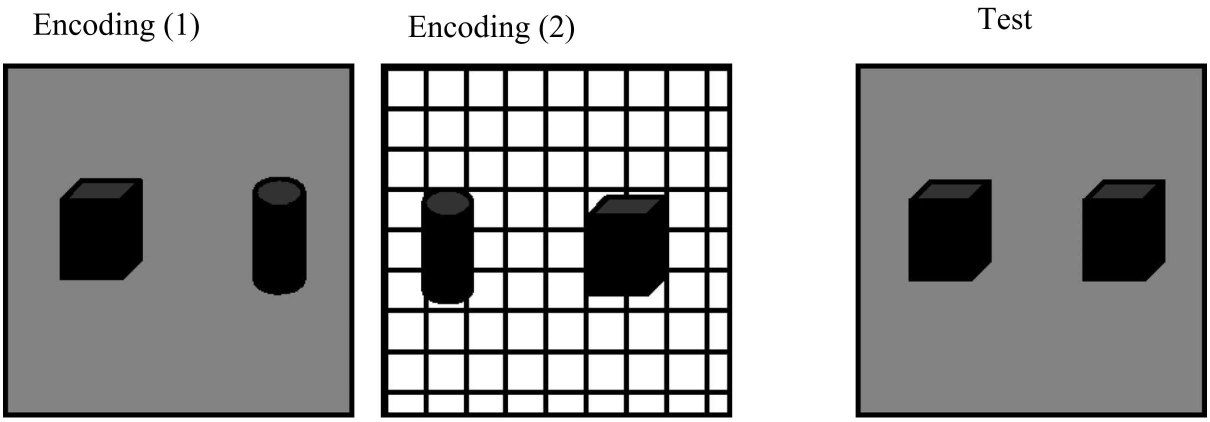
The scope of this chapter is to provide an overview of how we devised and refined the episodic task used throughout the experimental chapters in this thesis. The aim was to provide a content-based paradigm to assess episodic memory concisely, not verbally mediated, and therefore a novel candidate for use in children across a wide range of ages and neurodivergent groups such as autism spectrum conditions.

We evaluated the initial feasibility of a nonverbal episodic-like what-where-which memory task among adult students, a population where we know episodic abilities are mature. It would also allow us to gain crucial comparative information in future studies with autistic and non-autistic children.

The experiment used a modified version of the task by Holland and Smulders (2011) and Eacott and Norman (2004). Holland and Smulders (2011) investigated whether adults use episodic memory in an episodic-like memory task. Adults hid (where) two different coins (what) on two consecutive days (when) and were then tested for their memory of what was hidden, where and when. Participants were also asked *how* they recalled the information, i.e., did they remember or know? Remembering is associated with recollecting an event, reflecting episodic memory, whereas knowing gives a sense of familiarity, which is not considered episodic (Yonelinas, 2001). Participants in this task overwhelmingly reported a recollective experience of 'remembering' rather than 'knowing', suggesting accurate episodic retrieval in the WWW task requires autonoetic awareness because only 'remembering' would provide specific information from the studied event. Though this task was not a recognition task, it is not directly comparable with recognition studies using the remember/know paradigm that assesses conscious recollection. However, subsequent research using the WWWhich recognition task found that the subjective experience of remembering was associated with performance on the WWWhich task (Easton et al., 2012), supporting the view that the what-what-which relies on recollection and is a valid measure of episodic memory.

The WWWhich recognition task was developed initially by Eacott and Norman (2004) to assess episodic-like abilities in non-humans. In what-where-which tasks, an event is broken down into what happened, where it happened and on which occasion, using the context it was encoded in as a means to separate two events (rather than time as in WWW tasks). In the task (see Figure 2.1), they presented rats with two different objects in different orders and different spatial locations in two contextually (visual and textural) unique events (in this case, using different base textures and colours of the arena walls). In the first encoding phase, rats are presented with two different objects, one on the left and the other on the right of the arena in context 1. After exploring the objects in this context, the rat is removed for a brief delay. In the second encoding phase, the rat is returned to the arena, exposed to context two, and presented with the same objects as phase one, switched to the opposite location. For example, an object on the left in the first context would be on the right in the second context. After variable delays, the rats return to the arena (configured to one of the previously seen contexts) with two identical copies of the same object on the left and right of the arena, one of which will be novel and the other familiar. Critically, suppose the rat has encoded the two events as being separate. In that case, it should demonstrate a novelty preference for the object it has seen before but never in that location in that particular context. Results showed this is precisely what they found; rats spent longer exploring the integrated and novel combination of what they saw, where they saw it, and on which occasion it was seen. Demonstrating that they can distinguish the novel from the familiar object.

Figure 2.1 *Schematic of the Integrated Object, Place, and Context Task*



Note. The figure illustrates a schematic representation of the two encoding phases with two different objects and a test phase where they are exposed to two copies of the same object in a sample phase. In the example, the novel combination of object and context is the object on the right. Adapted from '*Integrated memory for objects, place, and context in rats: a possible model of episodic-like memory*?', by Eacott & Norman (2004) Journal of Neuroscience, 24, p. 1949. Copyright 2004 by The Society for Neuroscience.

Though successfully adapted for use with humans (Easton et al., 2012), its adaptation relies on pen and paper-based descriptions of responses to assess episodic-like memory, making it inappropriate for younger children irrespective of neuro divergences. Thus, the critical challenge was to develop a nonverbal solution informed by the existing design of behavioural content-based WWW and WWWhich tasks.

A key consideration in any endeavour to design materials for research with autistic children is sensory sensitivities. We know that in addition to the two overarching domains: social communication and restrictive, repetitive behaviours that merit recognition of an ASC, a range of other sensory features accompany the autistic experience to warrant inclusion as a diagnostic criterion in the DSM-5 (American Psychiatric Association, 2013). Compelling evidence suggests that autistic individuals experience sensory reactivity to sensory stimuli (Ben-Sasson et al., 2009). These are sensory hyperreactivity and sensory hyporeactivity. Hypersensitivity occurs when the stimulus feels too intense, e.g., lights seem overly bright/flickering, overpowering scents and sounds are too loud – thus, a need for avoidance to manage levels of distress and discomfort which may trigger self-stimulation (via sensory seeking) (Bogdashina, 2016). Sensory hyporeactivity (indifference to sensory information), on the other hand, manifests as not noticing sensory input (e.g., pain, hunger, temperatures) (Chamak et al., 2008; Elwin et al., 2012).

Autistic individuals may also be sensory seeking (repeatedly seeking sensory input) as a result of sensory hyperreactivity/under reactivity or as part of restrictive and repetitive behaviours (RRBs) (Lidstone et al., 2014; Pellicano et al., 2013; Schulz & Stevenson, 2019). Sensory sensitivities are a commonly reported feature in autism, with 42% to 88% of autistic children having sensory processing disorder (SPD) (Baranek, 2002). Moreover, sensory reactions can impair attention (Baranek, 2002; Tomchek & Dunn, 2007).

Given this need, we created an experimental set-up that provided enough visual information to distinguish one event from another highly similar one. Still, we avoided prominent sensory experiences that might upset/prompt sensory-seeking behaviours for the child, such as the use of sensory cues used in episodic memory research such as flashing lights (with non-autistic children; Burns et al., 2016) and odours (adults (with adults, e.g., Saive et al., 2013).

Bearing in mind the Executive function difficulties commonly reported in autism and the developmental appropriateness of using a long, complex task, it was important to make the experience meaningful but nonetheless brief in its duration. Executive function difficulties generally impact areas such as Inhibition, Attention, and Working memory. In addition, it was also important to consider anxiety in situations of uncertainty (anxiety is one of the top research priorities for autistic children; Autistica: Cusack & Sterry, 2016) as it can negatively impact several aspects of well-being; emotional, cognitive, and behavioural levels, when faced with uncertain situations and events (Rodgers et al., 2019). Therefore, ensuring we had an experimental set-up that was easily transportable was an important factor to consider to enable testing to take place in the child's familiar school setting.

There is also increasing awareness that individual differences in research, particularly in autism research where analyses often rely on group level, should be considered while designing studies. For example, consider studies where large standard deviations evidence individual variability in performance on episodic tasks. It would be helpful to know the characteristics of children (typical and autistic) that show fewer correct responses, while others do not determine whether that particular mechanism is associated with better performance on episodic measures for autistic children. Take, for example, executive functions, in particular, working memory capacity; if episodic abilities are correlated with individual differences in children's working memory (as has been previously shown with autobiographical memory- see Crane et al., 2013), this would suggest that working memory may constitute a common mechanism of individual differences in episodic memory. Unfortunately, as others have mentioned, details regarding individual differences in episodic abilities in autism research are often not reported (Crane et al., 2013).

Our version of the task was necessary to overcome these limitations and assess episodic memory in young children and neurodevelopmental populations to develop a content-based task but crucially non-verbal in its assessment. To establish the methodology, we tested adults because we know episodic abilities are present and mature.

The real-world task we used involved adults attending the laboratory twice on the same day to complete two encoding phases (each separated by an hour break) and a testing phase. We tested participants in one room divided into two distinct spaces: the moon and forest corners. Despite clear benefits to having two spatially distributed rooms (see Lourenco & Frick, 2014, for review), it was essential to respect and mitigate the problem of limited resources in many school-based settings; we chose as a priority to have a transportable experimental set-up that could be used within one room. This, therefore, represented a compromise between issues of practicality and feasibility. In everyday life, it is equally probable for different events to occur in the exact location (e.g., I remember eating breakfast this morning whilst sitting on the chair in my home instead of sitting on the same chair but watching TV in the evening). Equally, so can events in different locations (e.g., I can remember and differentiate between a heated discussion with a family member at my house and a get-together at theirs). Thus, both scenarios provide valid encounters to encode episodic memories. To this end, rather than hiding the items in locations spatially distributed throughout the room (as in the task by Holland & Smulders, 2011), adults hid six items at specific locations within each hiding apparatus in two contextually unique events (see Figure 2.2 for experimental set-up) as in Eacott & Norman, (2004). To reduce verbal demands, we tested the adults behaviourally for their recall; by asking them to find the hidden objects.

Iterative testing and refinement of solutions were necessary. To this end, experiment 1a investigates the effects of using ten boxes spatially distributed on a hiding apparatus (where) to hide six pens (what) in two encoding phases (one in context 1, the context 2 [which]) that are separated by a one-hour break. A behavioural recall test was followed to assess participants' episodic memory of the two events and their binding components (what-where and what-which) within the same paradigm. The hiding locations varied spatially on each apparatus and offered an interactive layout for participants to hide and retrieve objects. Because each hiding apparatus holds the same containers (each of the same colour, material, and shape), to accurately retrieve a specific object, a participant must rely on spatial information rather than the extrinsic qualities of the container. Experiment 1 influenced the final paradigm in Experiment 1b of this study, which investigated the effect of using a six-box condition with objects rather than pens. We formulated the following objectives to achieve the aims:

- To develop a design methodology that takes a nonverbal and content-based approach to assess what-where-which episodic memory (and its binding components) can be used with typically developing children across a wide range of ages (3-11 years) and autistic children and is transportable across sites.

Before evaluating EM in children, the aim is to test the methodology in adults (where we know episodic memory capabilities are present). In doing so, we further investigated its relationship with measures of subjective phenomenology associated with retrieval (the states of awareness accompanying retrieval; 'remember' vs 'know'), verbal memory, visual attention and task switching, inhibitory control, the vividness of visual imagery and working memory. Within-group correlational analyses were also conducted to explore potential associations between these variables.

2.2 Experiment 1a (10-Box)

2.2.1. Methods

2.1.1.1 *Participants*

Twenty-nine university students aged 19-23 years (*M* = 20.17, *SD* = 1.16) (22 female) were recruited from Durham and Newcastle Universities. Four participants were excluded; one was the only participant to experience a 12-box condition, and the other three were the only ones to experience objects other than pens. Therefore, the final sample for the current study comprised 25 students aged 19-23 years (*M* = 20.16, *SD* = 1.21; 19 female; 21 Durham University).

Participants were included in the study if they distinguished between the colours in the colour-naming task (see Appendix A) and had no known colour vision deficiency or developmental or neurological disorder. Undergraduates from the psychology department (at Durham and Newcastle Universities) were given research participation credits. In addition, students from other faculties were entered into a raffle to receive a £5, £10, or £20 Amazon/Starbucks gift voucher for their participation.

Durham University and Newcastle University's respective Psychological Research Ethics Committees approved ethical approval for this research. Participants were not made aware of the study aims before completion. However, all eligible participants provided informed consent and were debriefed. The experimental sessions took place individually in a quiet room within the laboratory at Durham or Newcastle University.

2.1.1.2 *Materials*

As well as the WWWhich task, participants completed a battery of assessments measuring cognitive performance on verbal memory, visual attention and task switching, inhibitory control, the vividness of visual imagery and working memory.

2.2.1.3 Apparatus

The hiding apparatus is a toy kitchen (W72 x D40 x H109cm) modified to contain sixteen possible hiding locations. Figure 2.2 shows the hiding apparatus and an example of the experimental set-up of the room. Each hiding apparatus is set within a specific context (Fig 2.2; Left image = ‘Forest’ context, right image = ‘Moon’ context. For the location component of the experiment, ten ([Exp 1a], or six, [Exp 1b]) identical (15 x 12.5 x 6.5cm) wooden flip-lid boxes were distributed spatially on the hiding apparatus. The arrangement of these boxes was pseudorandomised and depended upon the specific object-location-context configuration for each trial type (what-where-which, what-where, what-which). For example, in what-where-which information trials, the location of the boxes on each hiding apparatus differed (but the identity of the colouring pens was held constant). For what-where information, the location of the boxes differed in each hiding apparatus (different colouring pens were used). Lastly, in what-which information trials, the spatial location of the boxes was the same in each hiding apparatus (but with different colouring pens). Boxes that remained empty were always in the same locations on each hiding apparatus. A small table was present in the room, situated in front of the two contexts in a central position. This represented the starting point. On the table featured a piece of paper colour swatches (Exp 1a: Appendix G) to indicate which colouring pen the participant should select from the cup holder (or images of the objects [Appendix B]) that participants should select from a box.

Figure 2.2 *Example of Experimental Set-up*

Note: The two hiding apparatus were set within two separate contexts (Forest vs Moon) situated in the same room. The left panel demonstrates the Forest context. The right panel demonstrates the Moon context. For the location component of the experiment, ten ([Exp 1a], or six, [Exp 1b]) identical (15 x 12.5 x 6.5cm) wooden flip-lid boxes were distributed spatially on the hiding apparatus. The arrangement of these boxes was pseudorandomised and depended upon the specific object-location-context configuration for each trial type (what-where-which, what-where, what-which). For example, the location of the boxes on each hiding apparatus varied spatially on what-where-which and what-which trials but was held the same for what-which trials. Boxes that never contained an object featured identical locations on each hiding apparatus. A small table was present in the room, situated in front of the two contexts in a central position. This represented the starting point. On the table featured a piece of paper colour swatches (Exp 1a) to indicate which colouring pen the participant should select from the cup holder (Appendix G), or these were replaced with images of the objects [Appendix B]) that participants should select from a box (Exp1b).

2.2.1.4 What-Where-Which Task

Participants were unaware they would be taking part in a memory study. They were told we were investigating how well they could perform a verbal task (counting in ascending order, e.g., 123456) while carrying out a motor task (selecting colours and hiding them in containers. They were informed that we would be recording the sessions using an audio recorder to transcribe performance on the verbal task. Recent studies have shown that intentionality during the encoding phase affects recollection in adults (e.g., Holland & Smulders, 2011) and TD children (e.g., Martin-Ordas & Atance, 2019); therefore, no memorisation instructions were given. Furthermore, the articulatory suppression task (Hanley, 1997) prevented participants from verbally rehearsing any information that would later aid their recovery.

In both hiding sessions (each separated by a one-hour break), participants selected six different coloured pens (examples of the eight potential colours: red, orange, yellow, green, brown, black, blue, and purple) to hide in six different predetermined locations; six in context one, and six in context 2 (the 'moon/forest corner') (Figure 1). There was a cup holder with 16 coloured pens (two identical sets of eight colours) on a table located at a central point between the two toy kitchens, each set within different contexts in the same room. Next to the pens on the table was a sheet of paper with eight colour swatches of the different coloured pens that the participants had to select from the cup holder (Appendix G). The use of pictures was two-fold. First, to focus attention on the colour of the pens without actually instructing them to do so. Second, make the task less reliant on verbal instructions, necessary for future work with NT and autistic children. The pens were collected and hidden one at a time.

Finally, after completing the ancillary tasks (see below) during the last one-hour break, the participants showed the same set of colour swatches as seen previously in the encoding sessions. Participants were then asked to retrieve the hidden objects one at a time in the order indicated in the sheet as the experimenter pointed to them one by one. For WWW and WW trials, the experimenter pointed to an object and then took participants to the relevant context to find it. In contrast, in WWhich trials, participants were instructed to choose the context they would like to search.

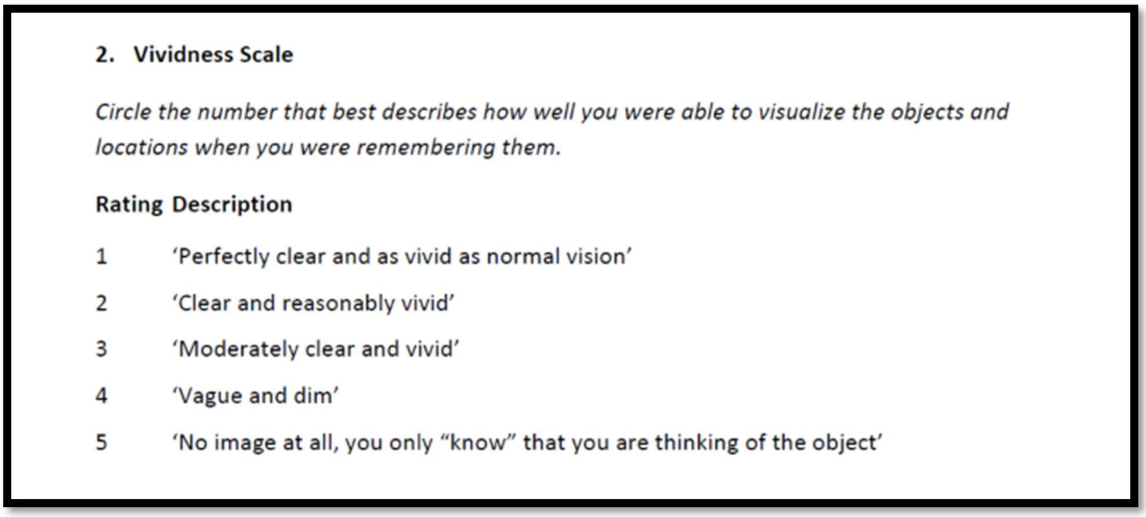
2.1.1.3 *Subjective Experience of WWWhich Recall: Experiential component*

This was administered immediately after the test phase of the WWWhich task. Participants reported how they recalled where they hid the pens. The questionnaire asked did they 1) "remember yourself moving around the hiding apparatus placing the pens in different locations" or 2) did you "know" where the pens were? Remembering is associated with episodic memory while knowing is related to semantic memory (Yonelinas, 2001).

2.1.1.4 *Vividness Visual Imagery Questionnaire (Marks, 1973)*

This self-report questionnaire (see Figure 2.3) was administered immediately after the subjective experience questionnaire. It involves asking participants to rate on a scale of 1 to 5 how vividly they re-experienced the hiding events (1 being perfectly clear and as vivid as normal vision; 5 being no image at all, you only know that you are thinking of the object) - time to administer 10 mins.

Figure 2.3 *Vividness Visual Imagery Questionnaire (Marks, 1973)*



2. Vividness Scale

Circle the number that best describes how well you were able to visualize the objects and locations when you were remembering them.

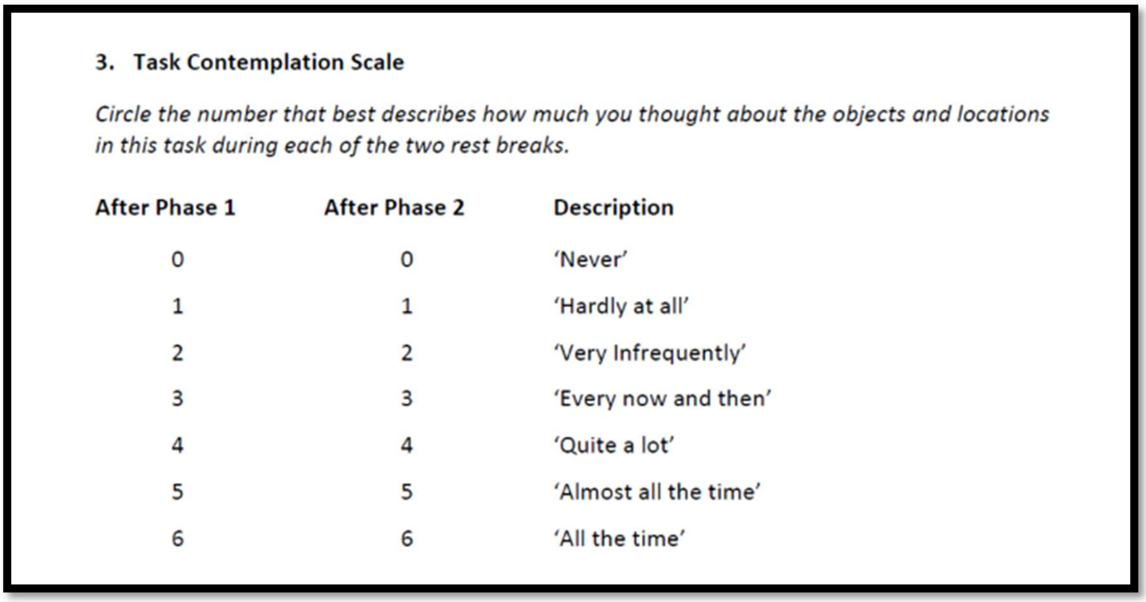
Rating	**Description**
1	'Perfectly clear and as vivid as normal vision'
2	'Clear and reasonably vivid'
3	'Moderately clear and vivid'
4	'Vague and dim'
5	'No image at all, you only "know" that you are thinking of the object'

Note. The figure shows the vividness scale used to assess the vividness and clarity of visual mental imagery. Participants rated their vividness of imagery on a scale of 1 to 5.

2.2.1.7 Task Contemplation Scale

Participants identified how much they thought about the objects and locations in the WWWhich task during each of the two rest breaks using a scale of 0 to 6 (0 being not at all and 6 – all the time [see Figure 2.4]). This was administered immediately following the vividness Visual Imagery Questionnaire.

Figure 2.4 *Task Contemplation Scale*



3. Task Contemplation Scale

Circle the number that best describes how much you thought about the objects and locations in this task during each of the two rest breaks.

After Phase 1	After Phase 2	Description
0	0	'Never'
1	1	'Hardly at all'
2	2	'Very Infrequently'
3	3	'Every now and then'
4	4	'Quite a lot'
5	5	'Almost all the time'
6	6	'All the time'

Note. The figure shows the task contemplation scale used to assess how much participants thought about the items and locations for the WWWhich task during the two rest breaks.

2.2.1.6 Inhibitory Control.

Stroop Colour-Word Test (Stroop, 1935). The Stroop Colour–Word Test was administered using a ten × eight grid (read across the rows 8). There were four conditions in which words, colours or letter strings were each repeated 20 times on each card in a pseudo-random order – never appearing more than twice in a row. For each subtest, there are 80 stimuli on a page, spatially configured as eight items per column (ten columns total). Participants are instructed to read the rows from left to right, beginning with the first line. The time taken to complete each subtest was recorded (as well as any errors).

Table 2.1 shows the four conditions: RCNb(Reading colour names printed in black); RCNd (Reading colour names while ignoring its print colour which was incongruent to the word, e.g., word **BLUE** printed in red ink); NC (Naming name the print colour of nonsense strings); NCWd (Naming colours of printed words ignoring the word itself, e.g., **RED** printed in blue ink, the aim is to name the ink-colour and ignore reading the word).

The word stimuli consisted of the four colour words red, green, orange, and blue (RGBO). Letter strings composed of the alphabet letters matched the length of the four different colour words (e.g., hjh for red). The letter strings and words were coloured in red, blue, green, and orange and appeared on a white background. Stimuli always appeared in a colour different from the word meaning or length of letter strings (except baseline condition). Thus, the word stimuli were always incongruent. The output of this test generated two measures of interference, with higher scores indicating worse function. First, the interference of conflicting colour stimuli (*RCNb-RCNd*). Second is the interference of conflicting word stimuli *(NC-NCWd)*. The latter represents Stroop's (1935) second experiment, where he found greater interference (slower response times and more error-prone) in colour naming time (NCWd) than was the case in the control condition (NC).

Table 2.1 *An illustration of the Stroop effect and the four conditions used.*

(1) Control RCNb	(2) Experimental RCNd	(3) Control NC	(4) Experimental NCWd
Red	Red	Hxy	Red
Green	Green	evgjc	Green
Blue	Blue	bhdr	Blue
Orange	Orange	gsxrqz	Orange

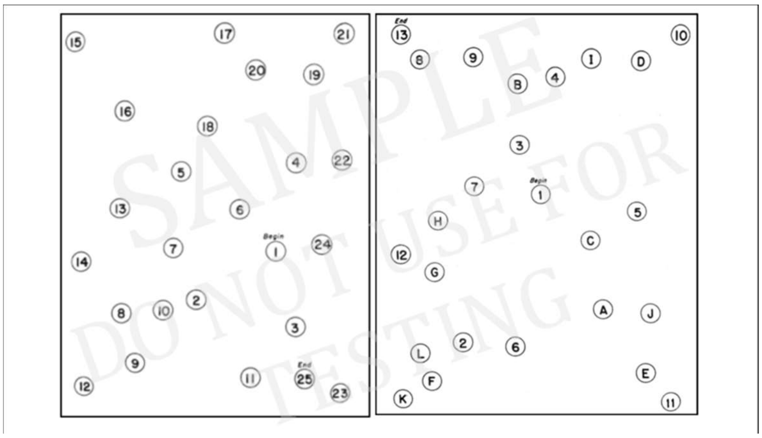
Note. In columns 1 and 2, the task is to read each word aloud as quickly as possible, ignoring its print colour. In columns 3 and 4, the task is to name the print colour of each word as quickly as possible, ignoring the word itself. RCNb = Reading Colour Names Printed in

Black Ink; RCNd = Reading Colour Names Where the Colour of the Print and the Word are Different; NC = Naming Colours (letter strings); NCWd = Naming the Colours of the Print of Words Where the Colour of the Print and the Word are Different.

2.2.1.7 Executive functioning.

Two-part Trail Making Test A & B (Lezak et al., 2004). The test has two parts (see Figure 2.5) to measure different cognitive processes (psychomotor speed and psychomotor speed plus executive functioning, respectively). In Part A, participants rapidly drew a line connecting digits (1-25) in ascending order (e.g., 1, 2, 3, and so forth) without lifting the pencil from the paper. In Part B, participants connected a series of circles including numbers (1 – 13) and letters (A – L); as in Part A, participants rapidly connected the circles in ascending order, but while alternating between the numbers and letters (i.e., 1-A-2-B-3-C, and so forth.). Performance is measured by calculating the difference in time taken to complete part B from part A (lower difference scores represent greater executive control).

Figure 2.5 *Sample of the Two-part Trail Making Test A & B (Lezak, 2004)*



Note. Sample of the Trail Making Test parts A and B. The left image demonstrates part A of the Trail Making Test, where participants are instructed to connect the circles in sequential order, beginning at number 1 and ending at 25. The image on the right demonstrates part B of the Trail Making Test, where participants are instructed to draw a line connecting the numbers and letters sequentially while alternating between the two (e.g., 1---A---2---B---3---C), beginning at number 1 and ending at number 13. Adapted from Reitan & Wolfson, (1993). The Halstead-Reitan neuropsychological test battery: Theory and clinical interpretation (2nd ed.). Tucson, Arizona: Neuropsychology Press.

2.1.1.5 **2.2.1.8 Rey Auditory Verbal Learning Test (R-AVLT; Rey, 1964)**

Rey Auditory Verbal Learning Test (RAVLT) is a neuropsychological instrument for evaluating episodic memory. This instrument is based on the interference produced by learning two-word lists consecutively and then recalling the first list immediately and after a delay (Lezak, 1995). The participant is presented with a five-trial presentation of a 15-word list (list A; Table 2.2). This list is read aloud at 1 second between presentations, and the participant is immediately asked to recall as many words as they remember. Following this, the participant is read a single presentation of a new list of 15 words (List B - interference list; Table 2.2), which they then are asked to recall immediately. After List B, the examiner then asks the participant to freely recall as many words as possible from the first list (A6) and then again after a 30-minute delay (A7). The RAVLT takes up to 15 minutes to administer and has a 30-minute interval. The output of this test generates several indices of performance which reflect various aspects of learning and memory: immediate recall (trial 1 of list A [A1]), total learning (total words recalled from the first five trials 1 to 5 of list A [A1 to A5]), susceptibility to interference; proactive interference (A1– List B), retroactive interference (A5-A6), delayed recall (trial 7 of list A [A7]); and forgetting rate (% retained after the 30-min delay between trials A6 and A7; higher numbers indicate greater forgetting).

Table 2.2 *Example of RAVLT Word Lists (Free Recall)*

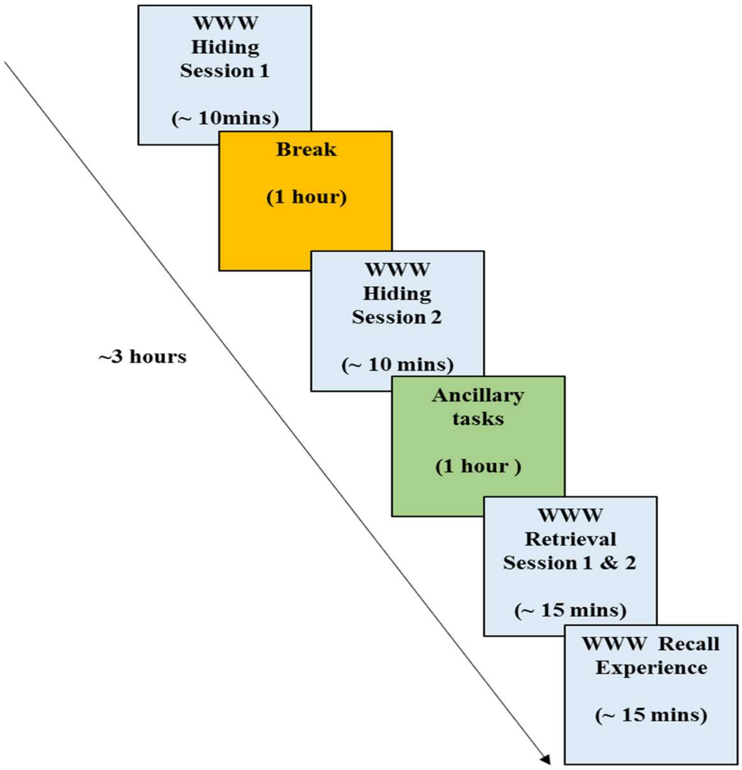
List A	List B
Drum	Desk
Curtain	Ranger
Bell	Bird
Coffee	Shoe
School	Stove
Parent	Mountain
Moon	Glasses
Garden	Towel
Hat	Cloud
Farmer	Boat
Nose	Lamb
Turkey	Gun
Colour	Pencil
House	Church
River	Fish

Note. List A = 15-word list learning task with five trials. List B = 15- new word interference list read to the participant after the fifth trial of List A.

2.2.1.9 Procedure

Participants attended the lab twice on the same day to complete two hiding trials (one in each half of the room [moon vs forest context]) and a testing trial. Participants were tested individually and performed the procedure in the same order with a total duration of ~2-3 h (see Figure 2.6 for a schematic of the process and Appendix D for the administration protocol). All trials were counterbalanced across participants based on trial type (WWWhich, WW and WWhich), context (moon vs forest) and locations.

Figure 2.6 *Schematic of the process (and duration) of each experimental test*



Note. Ancillary tasks refer to Stroop, Trail making A & B Task, and Rey-Auditory Verbal Learning Test.

Before the WWWhich task, each participant undertook a colour-naming task to confirm they had no known colour deficiency and identify the colours used in the EM task.

Colour naming task: The experimenter showed each participant a sheet of paper featuring eight easy-to-label colour swatches (see Appendix A). They then asked the participant to name the different colours independently.

Episodic What-Where-Which Task: Following the colour-naming task, The WWWhich task used a hide-and-seek paradigm that is a modified version of the real-world "What-Where-When" memory test developed by Holland and Smulders (2011) and the "What-Where-Which" memory test by Eacott & Norman (2004). In our task version, adults were tested individually across two hiding sessions separated by one hour. Participants were unaware they were completing a memory task; they performed a verbal articulatory suppression task (counting in ascending order, e.g., 123456) throughout the encoding sessions).

The experimenter told the participant that they should begin counting in ascending order once we entered the room to start the experiment. Once inside the room, the experimenter would direct the participant to the table, the starting point. The experimenter pointed to a piece of paper with colour swatches to indicate which coloured pen the participant should select from the cup holder. Once the participant picks up the pen, the experimenter would show the location to hide the pen by pointing to a particular box (which was closed) on the hiding apparatus within a given context. The participant would open the box, place the pen inside and close it before returning to the starting point to collect another coloured pen. The six different pens were hidden one at a time. Once all six pens were hidden in their predetermined locations within the hiding apparatus in the first context, the participant had a one-hour break.

The participant was returned to the room to complete the second encoding session, where again, they hid six different pens in six different predetermined locations in the same manner as in the first encoding session but this time in the other context. Participants also completed five ancillary tasks (see materials section for details). These were administered in the same order (Stroop, Trail-Making A & B, RAVLT), with the Rey Auditory Verbal Learning Test (RAVLT) always issued last.

To start the test phase, participants returned to the starting point at the table. There, the experimenter presented the participant with a sheet of paper featuring eight-colour swatches. Next, they were instructed to find the corresponding-coloured pen that the experimenter pointed to on the sheet (see Appendix F).

Each hiding episode used a unique set of colours to test EM for the first and another for the second (see Appendix G for example images). Thus, each experimental session was composed of three tests within the same paradigm (EM test, what-where and what-which binding components): (i) What-where Test involved using different coloured pens in different locations in each context - in this scenario, participants were instructed to find a particular coloured pen in a specific context (Figure 2b); (ii) What-Which Test involved using different coloured pens in each context but held their Spatial location constant (i.e., by using the same place in each hiding apparatus) - in this scenario participants had to decide whether to look in context one or context two depending on the colour of the pen they needed to find (Figure 2c); (iii) The EM Test involved the binding of what-where-which information, so the identity of the pen was held constant (by using the same coloured pen in both contexts), but the location differed (Figure 2a). The rationale for directing participants to look in a particular context was to ensure that participants could not achieve correct responses by relying on memory for the item or location alone – they had to integrate the three elements. Thus, demonstrating a coherently bound single representation of the unique combination of object-location-context, not the addition of what, where and when (Clayton, Bussey, Emery, et al., 2003; Clayton & Dickinson, 1998).

When participants retrieved a pen from a box, but it was the wrong colour, they left it in the box, and the experimenter moved on to the next colour (see Appendix H for the protocol for handling errors). Participants received a second opportunity to retrieve the coloured pen at the end of the retrieval session. Likewise, for cases where participants went to an incorrect location, but the box was now empty (false hit: either because they retrieved the pen in a previous attempt, or the box never contained a pen – empty), again, the participant was given a second opportunity to recover the pen. The experimenter recorded whether the participant retrieved the items either on the first/second attempt/not at all.

During the final retention interval of the WWWhich task, participants completed a battery of ancillary tests except for the episodic memory questions.

2.2.1.10 Analysis

In analysing the data, we were interested in the bound components of each trial: What-where, what-when and full EM (what-where-which). Therefore, participants' first searches were coded as one if correct and zero if incorrect. Then, each participant was provided two trials with the three test types (WWWhich, WW, WWhich), one corresponding to the first encoding session and the second. As such, order effects were not analysed. Instead, overall accuracy was determined by summing the scores for the two test trials for each of the three conditions: what-where-which, what-where and what-which binding combinations.

To compare performance against chance: we calculated chance levels according to the number of alternatives from which the choice was made. For example, the probability of retrieving the correct object is 1/10 (for the ten-box condition) on the first attempt; see working example in Table 2.3); however, this probability changes with each subsequent search. Once opened, the chance then decreases to 1/9). Chance levels also depend on the trial type; for what-which bindings, the participant needs only to choose the correct context (i.e., moon or forest corner) to score the trial correctly, therefore, in this instance, chance is 50/50 (1/2). Thus, considering all these factors, chance was calculated on an individual basis so that we ended up with each participant's probability of getting both trials correct, only the first trial correct, only the second trial correct, or none correct. We then calculated the chance of getting one or more events correct if we ran the experiment 100 times based on these individual probabilities. Then from this series of chance levels, we selected the highest chance value (i.e., this reflects the greatest possibility of someone doing well by chance alone). We then compared this chance value to the group's performance for each trial type (WWW, What-Where, but not for What-Which as this was the same for all participants).

To examine memory performance, we used the Generalised Estimating Equations (GEE), which extends Generalised Linear Models by allowing you to analyse data with a binomial distribution with repeated measures. We selected an exchangeable correlation matrix (this matrix structure is used for measurements from the same individual with no time dependence [time dependence would be used for pre/post designs]), specifying a binomial distribution with a logistic link.

Table 2.3 *Example of individual probabilities changing with each subsequent search.*

Trial Type	Context	Retrieved 1st Attempt / went to correct corner	Number of Boxes	Probability	Chance
WWW	Moon	no	10	1/10	0.10
What-Which	Forest	yes	10	1/2	0.50
What-Where	Moon	no attempt	10	1/9	0.11
WWW	Forest	no	10	1/8	0.13
What-Which	Moon	yes	10	1/2	0.50
What-Where	Forest	no	10	1/7	0.14

Note. The table shows a working example of how the individual probabilities were calculated based on the presence of 10 hiding locations and how these change with each subsequent search. An example of how these individual probabilities were used to calculate the chance of getting one or more trials correct for a full EM trial is as follows:

Two trials correct = .03 ([1/10 * 1/8]*2) by chance alone

One trial correct = .20 ([1/10 * 7/8] + [9/10*1/8]) by chance alone.

None correct = .79 **(**9/10*7/8) by chance alone

Therefore, based on 100 trials using these individual probabilities, the proportion of success, i.e., the chance getting one or both trials correct for a full EM tria,l would be .23 or approximately 23%.

2.2.2 Results

Table 2.4 shows the Sample Descriptive Statistics for Study Measures.

Table 2.4 *Means and Standard Deviations of Scores on Cognitive Measures 10-Box Condition*

Variable	**(*N*=25) Mean**	***SD***
Trail Making Test (TMT)		
TMT-A (sec)	32.93	10.26
TMT-B (sec)	56.72	25.26
TMT Difference (TMT-B-TMT-A)	-23.79	22.41
Stroop Colour Word Interference		
RCNb (sec)	31.84	3.68
RCNd (sec)	35.78	6.22
Interference of conflicting colour stimuli *(RCNb-RCNd)*	**-3.95**	4.13
NC (sec)	52.88	6.75
NCWd (sec)	76.23	18.23
Interference of conflicting word stimuli *(NC-NCWd)*	**-23.35**	14.59
Rey's Auditory Verbal Learning Test		
Immediate Word Span (A1)	9.24	2.52
Total Learning (Sum A1 to A5)	63	7.37
PI (A1-ListB)	.08	2.41
RI (A5-A6)	.48	1.39
Delayed Recall (A7)	13.60	1.71
FR (% Retained after 30-min delay between A6 and A7)	1.65%	10.95

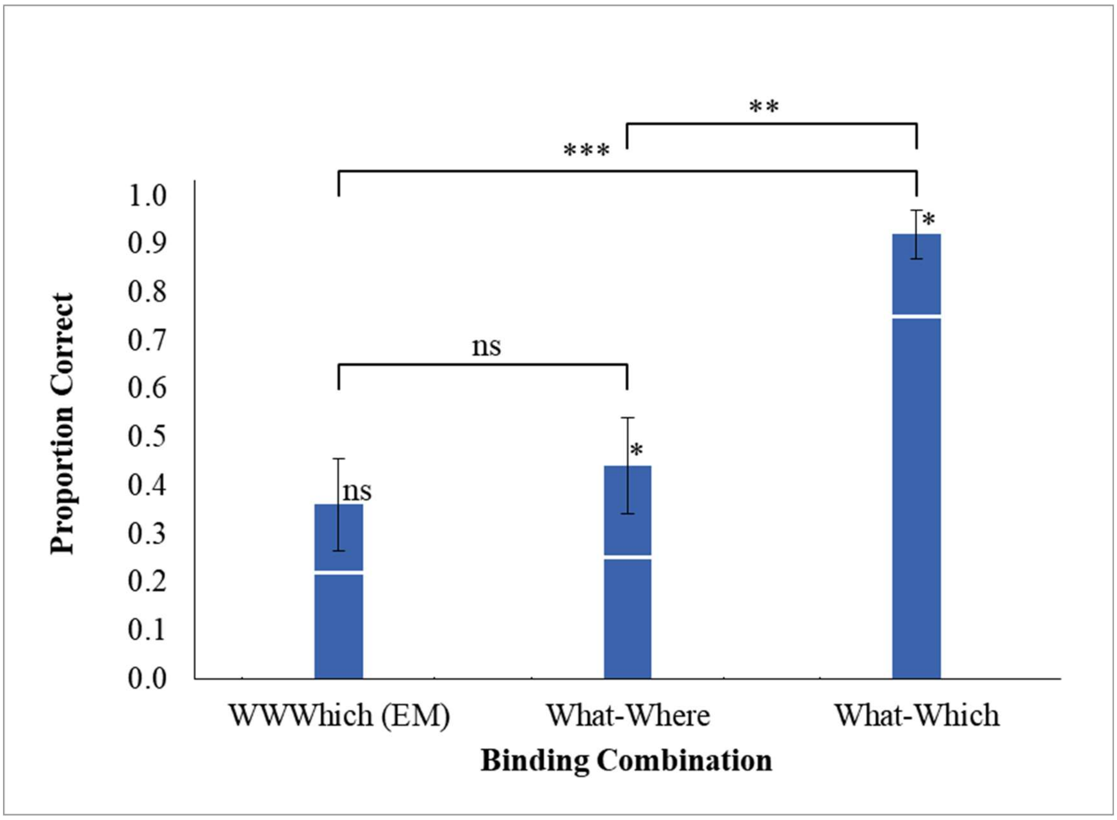
Note. RCNb = Reading Colour Names Printed in Black Ink (Baseline); RCNd = Reading Colour Names Where the Colour of the Print and the Word are Different; NC = Naming Colours; NCWd = Naming the Colours of the Print of Words Where the Colour of the Print and the Word are Different. See Appendix L for raw data table for performance on the WWWhich task and ancillary tasks in the 10-box condition.

2.1.1.6 **Preliminary analyses:**

We began by testing differences between accuracy (correct/incorrect) and differences in accuracy due to temporal order effects (i.e., accuracy for the events during the first encoding session and events in the second) for each trial type (WWWhich [EM], what-where and what-which). The results of the McNemar test revealed no significant differences in accuracy (correct/incorrect) between Time 1 and Time 2 for all three aspects of the WWWhich task (all p-values > 0.5). Hence, the analyses are collapsed across temporal order. Lastly, given that testing predominantly took place at Durham University ($N = 21$), we did not analyse differences in accuracy based on the testing site for the 10-box condition.

Chance: Figure 2.7 depicts that participants performed above chance on two of the three binding combinations (what-where, and what-which binding components) using a binomial test comparing the proportion of successes (i.e., correct responses, defined as getting at least one/more trials correct) with the most conservative estimate of someone doing well by chance alone; this was .22 for what-where-which [.36, $p = .079$, one-sided], .25 for what-when [.56, $p = .03$, one-sided] and .75 for what-which trials [.96, $p = .032$, one-sided]. Results of the McNemar Test showed a significant difference in the proportion of participants getting one or more trials correct when it came to remembering the what-which aspects of memory compared with the WWWhich (Episodic measure, $p < .001$) and the what-where binding component (p-values = .002).

Figure 2.7 *Memory Performance (across two trials) for different binding combinations in the 10-Box condition*



Note. The figure displays the proportion of successes (i.e., correct responses, defined as getting at least one/more trials correct) in the 10-box condition (*N* = 25) for each memory combination of the WWWhich task. White lines represent chance as proportions, set at .22, .25, and .75 for WWWhich, What-Where, and What-Which binding components, respectively. Asterisks above bars indicate comparisons to chance, while asterisks above difference lines indicate comparisons between binding combinations, *significant at $p \leq .05$, **significant at $p \leq .01$, ***significant at $p \leq .001$. Ns indicate that the results are not statistically significant. Error bars indicate the binomial standard error of sample proportion. Results of the Binomial test showed that memory performance was not significantly above chance levels for WWWhich, but was significantly above chance for the What-Where and What-Which binding combinations. Recall of the What-Which aspects of memory was significantly higher than recall of the WWWhich and What-Where binding components (McNemar test).

2.1.1.7 **Performance on the WWWhich Task:**

First, we examined the effect of trial type on memory performance. We conducted a Generalised Estimating Equation (GEE) analysis with accurate retrieval (yes or no) as the dependent variable and the three trial types (WWWhich, What-Where and What-Which binding components) and trial order (trial 1 and trial 2) as within-subjects factors. As we wanted to model those scoring correctly compared to those scoring incorrectly, we selected the reference category as zero. The non-significant interaction between trial order and trial type was removed. Results demonstrated memory performance was significantly predicted by trial type [Wald X^2 = 26.359, p <.001] with, on average, significantly lower levels of accuracy in the WWWhich (Wald X^2 = 17.873, p <.001) and WW (Wald X^2 = 21.253, p <.001). There was no significant effect of trial order (Wald X^2 = 2.311, p = .128).

Memory performance and cognitive functioning

To examine whether verbal memory performance and cognitive functioning predict memory success, we conducted a GZLM procedure for each trial type separately. We included measures from RAVLT, Trail AB, and Stroop task as covariates. Three measures from the RAVLT were used as covariates: the first was Immediate Word Span (A1), which measures how much information was freely recalled from the first exposure. Second, forgetting rate (number of words retained after a 30-min delay between A6-A7) as an indicator of storage capacity, and third, retroactive interference (A5-A6), which measures how susceptible participants are to interference after new information is introduced. Finally, as a measure of executive functioning (cognitive flexibility), the Trail AB score task (i.e., Difference between Trail A [psychomotor speed] and B [psychomotor speed plus executive control]) and Stroop interference effect (NC-NCWd = difference between the time taken to read colour words printed in black and the time taken to name colours of the printed words where the colour of the print and the word are different) were entered as covariates. Memory success was as entered as the dependent variable, occurring over a fixed number of two trials. None of the covariates was significant for WWWhich or WW binding combinations (p >.05). However, as shown in Table 2.5, inhibitory control, measured using the Stroop task, was predictive of memory accuracy [X^2 = 5.017, p =.025].

Table 2.5 *Parameter Estimates from the GLZM Analysis (WWhich) when accounting for Cognitive Functioning*

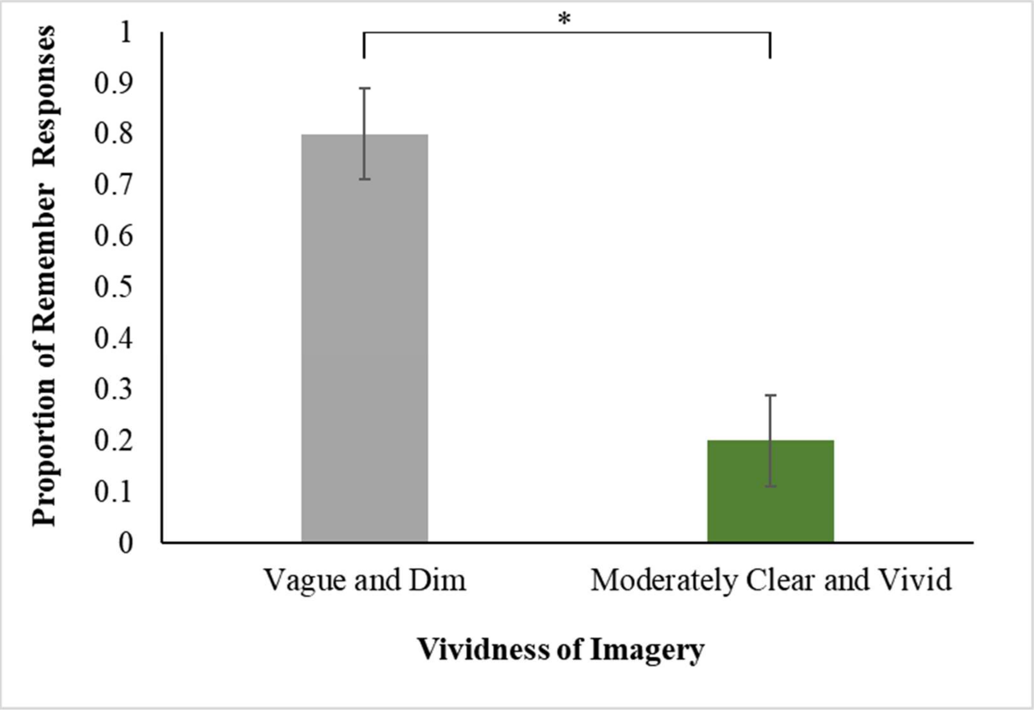
Parameter	*B*	Std. Error	Hypothesis Test Wald Chi-Square	df	Sig.	*Exp(B)*
RAVLT – Immediate Recall	.100	.1526	.430	1	.512	.820
RAVLT – Retroactive Interference	.276	.3129	.777	1	.378	2.065
RAVLT – Forgetting Rate	-.436	.3549	1.512	1	.219	.646
Trail (A-B) – Cog Flexibility	.010	.0159	.394	1	.530	1.010
Stroop – Inhibitory Control	-.075	.0335	**5.017**	**1**	**.025**	.928

Note. This table demonstrates the parameter estimates from the GZLM procedure for the 10-box condition (Exp 1a), examining the effects of the covariates on memory accuracy (0, 1, 2 trials correct) in the What-Which binding combination.

2.1.1.8 **The subjective experience of Memory Performance**

We examined whether memory retrieval (WWWhich) was associated with either R or K responses. Overall, participants reported remembering themselves moving around the hiding apparatus, placing the pens in different locations (‘remember’) significantly more often than just knowing where the pens were (‘know’) [Binomial Test: p = .004; in total *n* = 20/25]. Participants predominantly reported the vividness of the experience to be either moderately clear and vivid (*n* = 6) or vague and dim (*n* = 19). Results of the binomial test examining only those who reported to ‘remember’ the sessions showed they overwhelmingly reported the experience to be vague and dim on the vividness scale [p = .012; in total n = 16/20; Figure 2.8]. However, despite an overwhelming strategy of recollection (i.e., remember responses), a GZLM procedure using WWWhich memory success (none, one, both trials correct; occurring over a fixed number of two trials) and the subjective experience and vividness ratings as covariates found that subjective experience (Wald: X^2 = 1.729, p =.189) and vividness of the experience (Wald: X^2 = .657, p =.418) did not predict WWWhich memory success. This result was replicated for WW and WWhich memory success (all p-values >.05).

Figure 2.8 *Vividness ratings reported by participants with a “remember” strategy in the 10-box condition.*



Note. The figure displays the proportion of participants who reported experiencing a subjective sense of remembering (*n* = 20/25). Specifically, it shows the proportion of these participants who rated the vividness of their visual imagery as “vague and dim” or “moderately clear and vivid” (despite the availability of five different ratings on the scale). Results of the binomial test revealed that significantly more participants rated their visual imagery as “vague and dim” compared to “moderately clear and vivid”, with asterisks indicating significance levels (* $p \leq 0.05$). Error bars indicate the binomial standard error of sample proportion.

Qualitative feedback:

Table 2.6 shows anecdotal feedback from participants, which suggested difficulties in the WWWhich task centring across three main areas: the discriminability of the pens, the proximity and similarity of the boxes (locations) and attending to the different contexts. Comments also related to anticipating the purpose of the study. Critically, even if they expected it was a memory study, memorising the locations was impossible because the counting task prevented this.

Table 2.6 *Examples of the Qualitative Feedback from Students on WWWhich task*

Feedback	Frequency
Different objects would be better	2
Dispersed around the room	1
The proximity of boxes is an issue – could remember the general location	2
Remembered the pens but not the colours	7
Contexts are not that distinguishable	1
Ignored contexts	1
Boxes are visually the same, so complicated to differentiate	1

Anticipated it was a memory task, but counting prevented memorisation	6
Did not anticipate it was a memory task	9

Note. The table illustrates examples of the qualitative feedback received from students in the 10-box condition on the WWWhich task.

2.2.3 Discussion – Experiment 1a

Experiment 1a served to define and inform the final version of the what-where-which task in several ways. First, it aimed to validate an adapted version of the what-where-which task designed to assess episodic abilities. Episodic performance was the only binding combination not above chance levels using the following conditions: 10 boxes, pens as objects, and a 1-hour retention delay between encoding and retrieval. This finding, together with anecdotal feedback from participants indicated that the task was difficult, with particular issues noted for recalling the *colour* of the pens hidden, and suggested adjustments needed to be made. It was also apparent that when adjusting for individual differences in verbal memory, cognitive flexibility (Trail Making Test) and inhibitory control (Stroop), memory accuracy on what-which was influenced by inhibitory control. Thus, the following experiment aimed to reduce the difficulty of examining whether it would result in more robust memory accuracy in our paradigm.

3.9 Experiment 1b (6-Box)

As mentioned previously, experiment 1a yielded evidence that adults could display What-Where and What-Which memories in the 10-box condition of the task but not for episodic memory (i.e., WWWhich binding configuration). Feedback from participants suggested that the task was difficult because the pens were not dissimilar or unique enough to recall. Thus, experiment 1b tested whether we could reduce task difficulty without producing ceiling effects, resulting in more robust episodic memory in our paradigm. The following procedural changes were implemented. First, we reduced the available hiding locations from ten to six boxes, making them more varied spatially on each hiding apparatus. Second, we replaced pens with distinct toys (see Appendix G); we reasoned that this would make it easier to distinguish which object was in which location (box) in which corner. Third, to draw attention to the contexts and hiding locations (which could be at the back of the hiding apparatus), participants were first familiarised with the two contexts (e.g., by asking them to count the number of trees/stars on the banners). For the locations, we asked them to count the number of boxes that opened towards them and how many boxes opened the opposite way. Finally, participants stayed within the encoding context for the duration of the hiding session rather than walking back and forth from a central point to collect objects. The reasoning was to minimise the fragmentation of the experience.

2.3.1 Method

2.3.1.1 Participants

Twenty-five university students aged 19-35 years (*M* = 22.72, *SD* = 3.88) (19 female) were recruited from Durham and Newcastle University. None of the adults had participated in Experiment 1a.

2.3.1.2 Materials, Apparatus, Procedure

The apparatus, events, and procedure in Experiment 1b were identical to those in Experiment 1a with four exceptions. Firstly, before the start of the first encoding session, participants entered the experimental room and were taken to each of the contexts in turn and asked to count the number of trees [in the forest context] and stars [in the moon context], see

Appendix D for protocol). Secondly, to draw attention to the locations distributed around the hiding apparatus, we asked participants to count the number of boxes that opened towards them and how many opened the opposite way. Thirdly, rather than hiding coloured pens, participants hid six distinct toys (see appendix B for examples of objects). Lastly, six items were hidden in six boxes, with participants staying in the encoding context (rather than walking back and forth to collect items from a central point) until all six objects were hidden in each context in turn.

2.3.2 Results

Table 2.7 shows the Sample Descriptive Statistics for Study Measures in the 6-box Condition.

Table 2.7 *Means and Standard Deviations of Scores on Cognitive Measures*

Variable	**Mean**	***SD***
Trail Making Test (TMT)		
TMT-A (sec)	34.03	10.05
TMT-B (sec)	53.21	11.32
TMT Difference (TMT-B-TMT-A)	-19.174	11.21
Stroop Colour Word Interference		
RCNb (sec)	35.59	5.20
RCNd (sec)	43.59	10.60
Interference of conflicting colour stimuli *(RCNb-RCNd)*	**-8.00**	10.22
NC (sec)	55.35	7.61
NCWd (sec)	72.62	12.15
Interference of conflicting word stimuli *(NC-NCWd)*	**-17.27**	9.81
Rey's Auditory Verbal Learning Test		
Immediate Word Span (A1)	8.20	2.05
Final Acquisition (A5)	14.04	1.12
Total Acquisition (Sum A1 to A5)	59.96	6.72
Amount Learned (A5-A1)	5.84	1.94
Proactive Interference (A1-ListB)	1.00	2.29
Retroactive Interference (A5-A6)	1.04	1.46

Delayed Recall (A7)	13.16	1.79
Forgetting Rate (A6-A7)	-.16	.88

Note. RCNb = Reading Colour Names Printed in Black Ink (Baseline); RCNd = Reading Colour Names Where the Colour of the Print and the Word are Different; NC = Naming Colours; NCWd = Naming the Colours of the Print of Words Where the Colour of the Print and the Word are Different. See Appendix M for raw data table for performance on the WWWhich task and ancillary tasks in the 6-box condition.

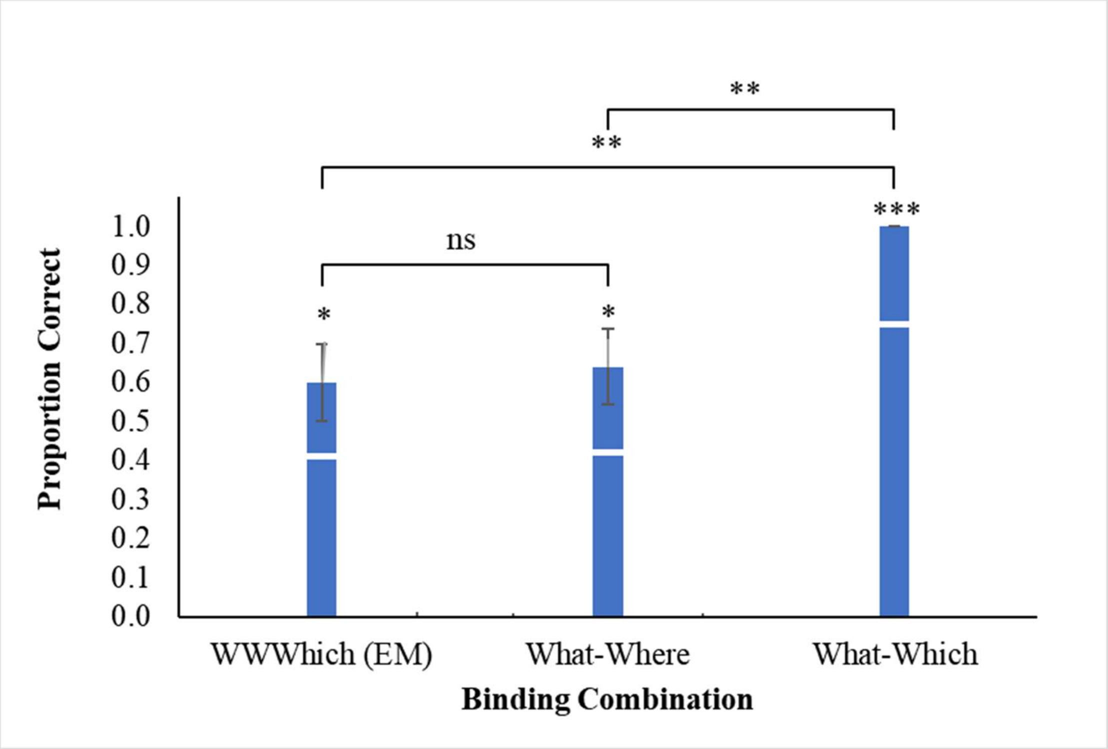
2.3.2.1 Preliminary analyses:

We began by testing for differences between accuracy (getting one or two trials correct or both incorrect) and testing site (Durham/Newcastle) using a Fisher's exact test. There were no significant differences between memory responses and testing site (Durham/Newcastle) for all three memory combinations (WWWhich, WW and WWhich) (all p-values > 0.5). We also tested for differences in accuracy due to temporal order effects (i.e., accuracy for the events during the first encoding session and events in the second). The results of the Fisher's exact test revealed no significant differences in accuracy (getting one, two or no trials correct) between Time 1 and Time 2 for all three memory combinations (WWWhich, WW and Wwhich) (all p-values > 0.5). Hence, the analyses are collapsed across the testing site and temporal order.

2.3.2.2 Performance in relation to chance:

Figure 2.9 depicts that participants performed significantly above the proportion expected by chance alone for all three binding combinations (WWWhich [EM], what-where, and what-which components) using a binomial test, with all *p*-values < .05. The binomial test compares the observed proportion of correct searches (i.e., getting one/both trials correct versus none correct [coded 0 and 1]) with the most conservative estimate of someone doing well by chance alone; see Table 2.8 for details). In addition, results of the McNemar test showed that a significantly higher proportion of participants recalled the what-which aspects of memory compared with the WWWhich (Episodic measure, p < .001) and the what-where binding component (p-values = .001; McNemar Test).

Figure 2.9 *Memory performance (across two trials) in relation to chance levels as a function of binding combination in the 6-Box condition*



Note: The graph shows the proportion of successes (i.e., correct responses defined as getting at least one/more trials correct) in the 6-box condition (N = 25) for each memory combination of the WWWhich task. White lines represent chance as proportions, set at .41, .42, and .75 for WWWhich, What-Where and What-Which binding components, respectively. Asterisks above bars indicate comparisons to chance; asterisks above difference lines indicate comparisons between binding combinations, *significant at $p \leq .05$, **significant at $p \leq .01$, *** significant at $p \leq .001$. Ns indicates that the results are not significant. Binomial tests showed that memory performance was significantly above chance levels for all memory combinations: WWWhich, What-Where, and What-Which trials. In addition, recall of the

What-Which aspects of memory was significantly higher than recall of the WWWhich and What-Where binding components (McNemar test). Error bars indicate the binomial standard error of sample proportion.

Table 2.8 *Table of Estimates for Chance Performance as a function of trial type*

Trial Type	Chance	
	One or more correct	None Correct
WWWhich	.41	.69
What-Where	.42	.68
What-Which	.75	.25

The table depicts the most conservative estimates of someone doing well by chance alone (proportion of successes defined as getting one or more trials correct versus getting none correct for each trial type).

2.3.2.3 Performance on the WWWhich Task:

First, we examined the effect of trial type on memory performance. We conducted a Generalised Estimating Equation (GEE) analysis with accuracy (scoring one, two or no trials correct) as the dependent variable and order (trial 1 vs trial 2) and the three trial types (WWWhich, What-Where and What-Which binding components) as the within-subjects factors. The trial type was entered as the predictor. The non-significant interaction between trial type and trial order was removed from the analysis. Results demonstrated no effect of trial order (Wald: X^2 =.725, p =.395). However, memory performance was significantly predicted by trial type [Wald: X^2 = 37.526, p < .001] with significantly lower levels of accuracy in WWWhich (*M* = .32 [*SE* = .057]: Wald: X^2 = 37.450, p <.001) and What-Where (*M* = .38 [*SE* = .077]: Wald: X^2 =20.886, p <.001) compared with What-Which task (*M* = .84

[*SE* = .046]). Pairwise comparisons revealed no significant difference in memory performance between What-Where and WWWhich tasks (p = .434).

2.3.2.4 Binding of What-Where and What-Which on WWWhich

To test whether performance on the WWWhich task was predicted by memory performance on the what-where and what-which task across the two trials. We then performed a GZLM analysis using performance on the WWWhich task (None, One, or Both Trials Correct) as the dependent variable (with a fixed value of two trials) and what-where and what-which entered as covariates. Results showed that performance on the WWWhich task was independent of adult participant's accuracy on What-Where (Wald X^2 = .663, p = .415) and what-which tasks (Wald X^2 = .330, p = .566), nor was there and interaction between the two binding combinations (Wald X^2 = .283, p = .595).

2.3.2.5 WWWhich Recall and cognitive functioning (inhibitory control and executive function):

To examine whether verbal memory performance and cognitive functioning predict memory success, we conducted a GZLM procedure for each trial type separately. We included measures from RAVLT, Trail AB, and Stroop task as covariates. Three measures from the RAVLT were used as covariates: the first was Immediate Word Span (A1), which measures how much information was freely recalled from the first exposure. Second, forgetting rate (number of words retained after a 30-min delay between A6-A7) as an indicator of storage capacity, and third, retroactive interference (A5-A6), which provides a measure of how susceptible participants are to interference after new information is introduced. Finally, as a measure of executive functioning (cognitive flexibility), the Trail

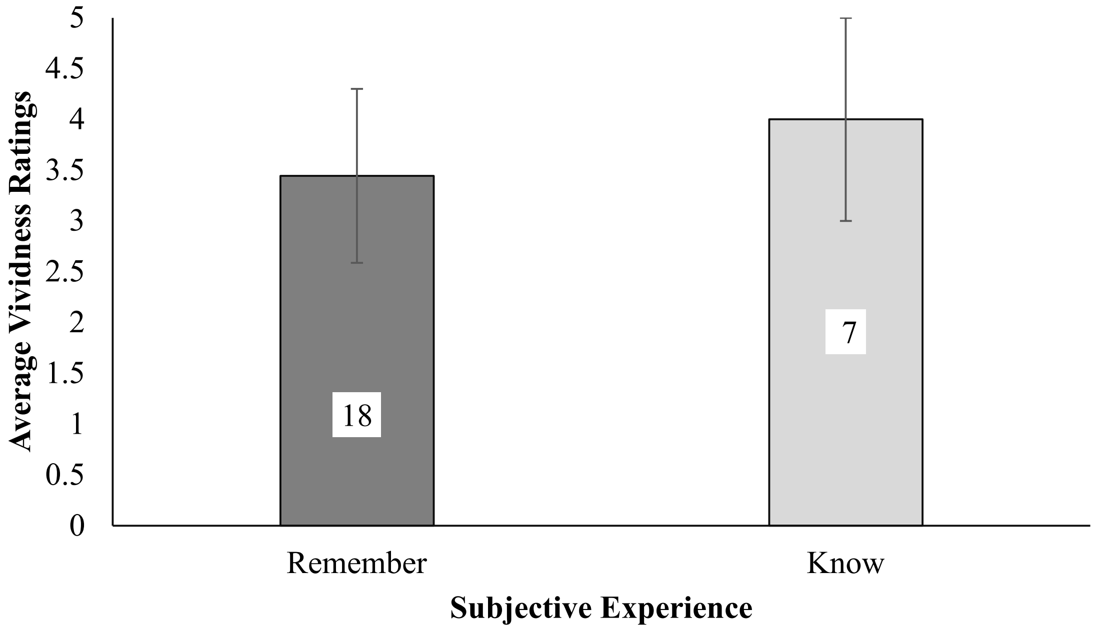
AB score task (i.e., Difference between Trail A [psychomotor speed] and B [psychomotor speed plus executive control]) and Stroop interference effect (NC-NCWd = difference between the time taken to read colour words printed in black and the time taken to name colours of the printed words where the colour of the print and the word are different) were entered as covariates. None of the covariates was significant for WWWhich, What-Where (all p-values >.05).

2.4.2.6 *The subjective experience of WWWhich Recall:*

Overall, participants reported remembering themselves moving around the hiding apparatus, placing the toys in different locations (remember) significantly more often than just knowing where the objects were (know) [Binomial Test: p = .043; in total 18/25]. Results from a Mann-Whitney *U* test showed that participants that reported "remembering" did not rate their visual imagery experience on the VVIQ as significantly different (*M* = 3.444, *SD* = .856) to those reporting to "know" (*M* = 4.000, SD = 1.000; [Figure 2.10]).

To examine the influence of vividness ratings and subjective experience on memory success, we conducted a GZLM procedure for each trial type separately. We included R/K responses (subjective experience) and vividness ratings as covariates. Results showed that participants with increasing vividness of the experience were more accurate on the WWWhich task (Wald X^2 = 4.274, p =.039,) while subjective experience had no significant effect on accuracy (Wald X^2 = .064, p =.800). For WW and Wwhich binding configurations neither vividness ratings nor subjective experience predicted memory success (all p-values >.05).

Figure 2.10 *Average Vividness Ratings as a Function of Subjective experience (R/K)*



Note: The bar graph shows the average vividness score of participants in the 6-box condition (*N* = 25) who reported re-experiencing the event subjectively as 'remember' (*n* = 18) and those who simply knew the information ('know', *n* = 7). The participants' visual imagery experience was rated on the VVIQ, with higher scores indicating greater vividness. The error bars indicate the standard deviations. Results from a Mann-Whitney *U* test indicated that there was no significant difference in vividness scores between the 'remember' (*M* = 3.44, *SD* = 0.86) and 'know' (*M* = 4.00, *SD* = 1.00) groups (*U* = 330.5, p = .10, *r* = -.16).

Accuracy comparison between 10-box and 6-box condition

We explored the data further by conducting a Mann-Whitney U test to examine whether making the task easier to do by chance alone in the 6-box condition compared to the 10-box condition resulted in greater overall levels of accuracy. Results showed that accuracy levels were not significantly higher in the 6-box condition for WWWhich (*W* = 248.000, p = .081; one-tailed) or Wwhich (*W* = 243.000, p = .058; one-tailed) trials; however, performance was increased for the WW task (*W* = 227.500, p = .038; one-tailed).

Qualitative feedback:

Table 2.9 shows anecdotal feedback from participants suggesting difficulties centring across three main areas: the discriminability of the pens, the proximity and similarity of the boxes (locations) and attending to the different contexts. Comments also related to anticipating the purpose of the study. Critically, even if they expected it was a memory study, memorising the locations was impossible because the counting task prevented this.

Table 2.9 *Examples of the Qualitative Feedback from Students on WWWhich task*

Feedback	Frequency
Would be better if dispersed around the room	1
The proximity of boxes is an issue – could remember the general location	2
Contexts are not that distinguishable	1
Ignored contexts	1
Boxes are visually the same, so complicated to differentiate	1
I anticipated it was a memory task, but counting prevented memorisation	6
Did not anticipate it was a memory task	9

Note. The table illustrates examples of the qualitative feedback received from students in the 6-box condition on the WWWhich task.

2.3.3 Discussion Experiment 1b

The results from Experiment 1b demonstrated that reducing the number of boxes from 10 to 6-boxes resulted in a task that, while easier to do by chance alone based on having higher chance levels, did not result in higher overall levels of accuracy in the 6-box condition for the episodic (WWWhich) and Wwhich elements of the task, though accuracy was greater for WW but not at ceiling. It was also apparent that individual differences in verbal memory (RAVLT), cognitive flexibility (Trail Making Test) and inhibitory control (Stroop) did not predict whether participants succeeded on the task or not. However, how vividly participants re-experienced events predicted success for episodic memory, with those recalling more vividly showing greater accuracy.

3.9 General Discussion

This study sought to modify two existing behavioural episodic tasks by reducing its reliance on spoken language, making it developmentally appropriate to assess episodic memory in autistic and non-autistic children between the ages of 3 and 11 years. The task used represented a situation where participants with mature episodic abilities might be expected to deploy episodic abilities (i.e., incidentally encoding episodic memories in a real-world task). This was the first time this assessment was used on adult participants.

As well as showing this task to be feasible in this population, it demonstrated that this was the case for the 6-box condition performing above chance levels. Furthermore, the trial type was a significant predictor of memory success in both conditions. This perhaps reflected the different chance levels associated with each trial type, with higher scores demonstrated in what-which trials in both conditions (though chance levels were higher, indicating performance was not necessarily better).

The analyses of cognitive functioning in both conditions revealed that the only measure of cognitive functioning independently predictive of memory success was inhibitory control (measured using the Stroop test reflecting prepotent response inhibition), and only for the 10-box condition. Response inhibition refers to the ability to suppress a dominant response. Selectively retrieving a memory among related memories requires inhibitory control to protect the contents of working memory from irrelevant information interfering (Friedman & Miyake, 2004). Working memory, in turn, is also a significant predictor of response inhibition in young children (Traverso et al., 2015). In the current study, participants needed to retrieve memories and keep track of them to shift the course of ongoing activity to choose a hiding location out of a possible 10 (Exp 1a) or 6 (Exp 1b) locations. Thus, being able to selectively inhibit prepotent responses (protecting WM from interference in the process) in the current 10-box condition may be particularly important. This could be because of the increased number of hiding locations to choose from – which essentially made the task more difficult because of spatial interference and also because the task was harder to do by chance alone (evidenced by the lower chance levels for the 10-box condition). This finding implies that the 10-box condition was more cognitively demanding, requiring inhibitory control, influenced by working memory, to maintain the different objects and available hiding locations to make a decision. Moreover, increased memory vividness predicted better memory outcomes but only in the 6-box condition. Research suggests that the phenomenological experience of vividness of imagery can influence recall performance by making incidentally encoded episodic memories more accessible to consciousness and facilitate access to long-term memories (D'Angiulli et al., 2013).

These aspects of the 10-box condition, together with the positive influence of vividness ratings, serve to increase our confidence that the 6-box condition may be more developmentally appropriate for use with children (autistic and non-autistic).

3 Exploring EM in Non-Autistic Children

A sample of 51 children between 3 and 6 years was tested on the what-where-which EM task developed in Chapter 2.

3.9 Introduction

As discussed in Chapter 1, the literature relating to episodic abilities in children is challenging to interpret, specifically about young children and those with neurodevelopmental diagnoses, because the tests used to assess episodic abilities rely on language ability to some extent. As a result, the literature more broadly might underestimate the episodic abilities of young children and autistic children when they need to respond to open-ended or structured interview-style episodic tasks where the level of detail provided differentiates between those with and without considerable difficulties in episodic memory (with less emphasis on overall accuracy). Due to this reliance on verbal ability in episodic tasks, there is minimal understanding of the emergence of the skill through infancy and childhood towards adult capacity.

Chapter 2 sought to address these difficulties – adapting previous work (Easton et al., 2012; Holland & Smulders, 2011) for use with children, we explored episodic memory in adults in a series of two experiments with a task that closely resembles the situations in which episodic abilities are encoded in daily life; passively. An essential strength of using such minimal content-based tasks lies in their utility to characterise episodic skills from the fundamental associative elements of episodic-like memory documented in children up to and beyond the more sophisticated form of EM demonstrated by adults. This ability to look separately at memory for some of the bound elements (what-where and what-which occasion) forming full episodic cognition (here, what-where-which occasion) may help identify the mechanisms underpinning how EM develops, the ages at which these critical associations emerge and reach maturity- and help to address the question of how they change with age when EM begins to decay.

Chapter 2 used two versions of the same behavioural what-where-which occasion task to assess episodic memory (and its binding combinations). One used ten hiding locations (using colouring pens as the object), and another with six hiding locations (using toys as the object). Both experiments showed that while adults demonstrated overall – above-chance levels of memory performance (for all binding combinations) in both versions of the task, it was the six-box version with toys as objects that were less dependent on executive skills making the six-box task easier without compromising performance.

One of the critical questions governing the current research is whether the what-where-which occasion EM task developed in chapter 2 can be used to assess episodic abilities in children and, if so, examine the emergence of episodic memory (along with an assessment of the binding of what-where, and what-which elements) in relation to developmental changes in cognition that occur during childhood. For example, is)? An assessment of the binding of these elements may help identify the mechanisms underpinning how EM develops, the ages at which these critical associations emerge and reach maturity, and help address how they change with age.

The current study uses the six-box variant of the real-world episodic task developed in Chapter 2 with further adaptations for children to answer these questions. For example, it was better to use toys as objects for adults because we reasoned that colouring pens might be less unique for adults and involve more of a shared identity of being 'pens' rather than individual and distinct colours. This might not be the case for children. Colouring activities in various forms provide an additional tool to focus attention in children (Beckwith, 2014). Colouring activities are also frequently used in schools to teach children sensorial concepts such as colour and improve fine motor skills (Stewart et al., 2007). We reasoned, therefore, that colouring pens might be more meaningful and motivational to children than to adults and would be beneficial to reintroduce in the current study. A second consideration that strengthened this decision was that colouring pens could also be used in a structured colouring task allowing us to identify children’s memory for what-where-which occasion memory (and its binding components) in a manner that does not rely on spoken language. When implemented, the value and added advantage of using colouring pens in a colouring task were functionally relevant to this thesis’s overarching purpose: to devise a minimally verbal episodic assessment that can be used with children of diverse ages and neurodevelopmental conditions.

A second adaptation in the current study with ’hildren concerned the articulatory suppression task. In chapter 2, an articulatory suppression task was used concurrently in the what-where-which occasion task because it interferes with inner speech (Gaillard et al., 2012) through loading the phonological loop capacity (Baddeley, 2007). This prevented adults from keeping track of what object was placed where and in which context. Inner speech, which peaks between the ages of 4 and 7 years (Winsler et al., 2009), is involved in cognitive processes such as memory and cognition (Alderson-Day & Fernyhough, 2015) and supports tasks that require considerable mental effort (Gaillard et al., 2012). Consequently, we reasoned that performing a dual-task (counting in ascending order while hiding colouring pens concurrently) would require more cognitive resources for children. As a result, children were not required to complete an articulatory suppression task in the current study.

In our child’s version of the task, children completed the what-where-which occasion EM task and other cognitive assessments across three separate days to minimise the amount of time that children were tested. This was to both maintain their levels of attention and listening and minimise disruption to their regular routines. In the What-Where-Which occasion EM test (henceforth, WWWhich), children hid six different coloured pens in six separate predetermined locations within a toy kitchen, three in context one, then three different coloured pens in context two. After a brief retention interval, children behaviourally located what item was hidden where (what-where test event), what item was hidden in which context (what-which event) and what item was hidden where in which context (one/two) (what-where-which EM test). The WWWhich EM Test required the binding of information for item identity (‘what’), spatial location (‘where’), and the physical context (‘which occasion’) into one representation. By separately analysing bound components within the EM Test, it was possible to investigate further the memory-binding processes for item-location and item-context on EM representation. EM follows a protracted developmental course improving until adolescence (Newcombe et al., 2007). However, the different components within an EM also develop at different rates, with the ability to recall the content developing earlier than spatiotemporal context (Picard et al., 2012) and, in addition, requiring age-related improvements in binding (Sluzenski et al., 2006). Therefore, based on the evidence outlined above, looking separately at bound components would examine the underlying mechanisms responsible for EM abilities and relate this to emerging cognitive abilities.

Based on the relevant developmental literature outlined previously, we explored: (i) whether using a minimally verbal what-where-which occasion task exploring contextual episodic memory in neurotypical children across a wide range of ages would lead to a revaluation of their capabilities when language confounds associated with free-recall tasks are reduced. In line with earlier research (Hayne & Imuta, 2011; Newcombe et al., 2014), we predicted that even our youngest children (3 years) should recall episodically, improving gradually with age; (ii) whether success on the episodic memory (WWWhich occasion) task is underpinned by age-related improvements in binding item to occasion/location. Previous research suggests spatial and temporal information scaffolds episodic memory performance in WWW tasks. However, because all three memory measures within the same paradigm (i.e., WWWhich, what-where, what-which) require contextual binding, with only WWWhich and What-Which involving associating information with temporal contexts, a defining feature of EM (Tulving, 1972), we hypothesised that these would show gradual age-related improvements; (iii) whether episodic memory ability in the current task is supported by developments in other domains of cognitive functioning such as developments in visuospatial working memory and visual short-term memory. Though working memory and episodic memory are predominantly studied in isolation (Lugtmeijer et al., 2021), previous research (Plancher et al., 2018) suggests that visuospatial working memory is important for temporal context. However, given the comparable binding demands in the current task for WWWhich, what-where and what-which, we speculated that visuospatial working memory would facilitate recall on all three tasks but made no firm predictions to what extent these might differ.

Therefore, the objective of the present study was to explore these hypotheses using a minimally verbal paradigm in a more ecologically valid and developmentally appropriate paradigm than traditional measures of episodic memory.

3.2 Method

3.2.1 Participants

Fifty-eight children (22 female) were recruited for this study. Participants were aged between 3 and 6 years (*M* = 5.36 years, *SD* = .97), with estimated IQ ranging from 70 to 140 (*M* = 98.48, *SD* = 15.52) as measured by the WPPSI-IV (Wechsler, 2012). All participants were recruited through local mainstream schools and from Durham University families' database and the developmental science research group's Facebook page. Parents completed the Social Difficulties Questionnaire (SDQ: Goodman, 1997). On this measurement, four participants scored above the cut-off of 11 on the total difficulties score. Parents confirmed no neurological or neurodevelopmental condition diagnoses in a separate bespoke screening questionnaire. One parent reported that their son/daughter had a neurodevelopmental condition on this measure. On this measure, one parent reported that their son/daughter had a neurodevelopmental condition. In addition to these exclusions, it was impossible to obtain full datasets for all eligible participants; reasons included voluntary withdrawal during testing (*n* = 2). As shown in Table 3.1, the final sample included fifty-one participants.

Ethical approval for this research was approved by the Durham University Psychology Research Ethics Committee. Parents provided informed consent, and all of the children provided assent before taking part. The experimental sessions took place individually in a quiet room either at their school or within the laboratory at Durham University.

Table 3.1 *Descriptive Statistics for the Developmental and Background Variables of Participants*

Developmental variables	*N*	*M*	*SD*	Range
Gender				
Female	22			
Male	29			
Age	51	5.41	0.99	3.04 – 6.92
3-years	6	3.52	0.35	3.04 – 3.93
4-years	11	4.63	0.15	4.47 – 4.89
5-years	16	5.56	0.22	5.22 – 5.93
6-years	18	6.41	0.28	6.00 – 6.92
Full-Scale IQ	51	102.55	13.09	77 – 140
VCI	51	103.55	12.39	72 – 139
VSI	51	103.20	14.14	77 – 138
VAI	51	103.33	12.14	83 – 136
NVI	51	101.61	13.42	77 – 146
WM	51	101.39	14.35	75 – 124

Corsi-Block	45	1.80	0.99	0 – 3.80
JND	51	19.00	3.81	4 – 24

Note. This table demonstrates the participant characteristics and developmental variables of the final sample of participants ($N = 51$) included in the study.

[a] **Full-scale IQ** = Full-scale IQ, four subtest version, derived from the Wechsler Preschool and Primary Scale of Intelligence – Fourth Edition (WPPSI-IV) (Wechsler, 2012), where the mean score is 100, and the standard deviation is 15;

[b] **VCI** = Verbal comprehension index derived from the (WPPSI-IV) (Wechsler, 2012), where the mean score is 100, and the standard deviation is 15;

[c] **VSI** = Visual-Spatial index derived from the (WPPSI-IV) (Wechsler, 2012),

[d] **VAI** = Vocabulary acquisition index derived from the Wechsler Preschool and Primary Scale of Intelligence – Fourth Edition (WPPSI-IV) (Wechsler, 2012), where the mean score is 100, and the standard deviation is 15;

[e] **NVI** = Nonverbal IQ: Perceptual reasoning index derived from the WASI-II (Wechsler, 2011);

[f] **WM** = Working memory index derived from the Wechsler Preschool and Primary Scale of Intelligence – Fourth Edition (WPPSI-IV) (Wechsler, 2012), where the mean score is 100, and the standard deviation is 15.

[g] **Corsi-Block**, a measure of visual-spatial working memory = Data are reported for children above 3-years ($N = 45$).

[h] **JND** = size Just-noticeable difference task, a measure of short-term memory

3.2.2 Materials

Participants completed a battery of standardised assessments measuring performance on a range of cognitive tasks, providing scores of full-scale IQ and tasks that measured episodic memory, visual short-term memory (size Just-Noticeable Difference Task) (Hamilton et al., 2018) and non-verbal spatial working memory (Corsi-block task; Corsi, 1972, computerised Corsi version; Hamilton, 2017).

3.2.3 Apparatus

The hiding apparatus is a toy kitchen (W72 x D40 x H109cm) modified to contain six possible hiding locations. Figure 3.1 shows the hiding apparatus and an example of the typical setup of the room.

Figure 3.1 *Example of the Experimental Set-up used in the What-Where-Which Task*

Note. The two hiding apparatuses were set within two separate contexts (Forest vs Moon) situated in the same room. The left image demonstrates the Forest context. The right image shows the Moon context. For the location component of the experiment, six identical (15 x 12.5 x 6.5cm) wooden flip-lid boxes were distributed spatially on the hiding apparatus. The arrangement of these boxes was pseudorandomised and depended upon the specific object-location-context configuration for each trial type (what-where-which, what-where, what-which). For example, the location of the boxes on each hiding apparatus varied spatially on what-where-which and what-which trials but was held the same for what-which tests. Boxes that never contained an object always featured in identical locations on each hiding apparatus. A small table was present in the room, situated in front of the two contexts in a central position. This represented the starting point. The table featured a piece of paper with images of the colouring pens to indicate which colouring pen the participant should select from the cup holder.

3.2.4 What-Where-Which Task

Before the What-Where-Which Task, each child undertook part in a colour-naming task and a familiarisation session.

3.2.4.1 Colour naming task

The experimenter showed each child a sheet of paper featuring eight easy-to-label colour swatches (see Chapter 2, Appendix A). They then asked the child to name the different colours independently. This task was to ensure that children were able to identify the colours used in the EM task.

3.2.4.2 Familiarisation task

Once participants successfully named the colours in the colour naming task, all children participated in a warm-up session to become familiar with the main what-where-which task and promote engagement positively. The experimenter showed children a pair of identical containers and two different objects they could handle in this session. The experimenter then instructed the child to hide the objects in each box and close the lids (see Figure 3.2). Once the child had done this, they were shown a picture of the two hidden toys (See Appendix E) and asked, “Where did we hide [points to and labels one of the toys]? Can you show me where it is?" If the participant struggled to understand or failed to find the toy correctly, the experimenter repeated the familiarisation phase while emphasising the relevant information. Only if the child identified the colours used in the colour naming task and demonstrated that they understood the procedure in the familiarisation task did we commence with the episodic task.

Figure 3.2 *Examples of Stimuli used in the Familiarisation task*

Note. This image shows the two pairs of identical containers and two different objects that were used in the familiarisation task. In the familiarisation task, children hid the two objects, one in each box and then closed the lids. Then, they were shown a photograph of the images and asked to find the toy the experimenter pointed towards.

3.2.4.3 What-Where-Which Task (Episodic Task)

The WWWhich task used a hide-and-seek paradigm that is a modified version of the real-world "What-Where-When" memory test developed by Holland and Smulders (2011) and the "What-Where-Which" memory test by Eacott and Norman (2004). Children were tested individually across two consecutively run hiding sessions in our task version, lasting approximately 10 minutes. In both hiding sessions, participants selected six different coloured pens (examples of the eight potential colours: red, orange, yellow, green, brown, black, blue, purple) to hide in six different predetermined locations; three in context one and three in context 2 (the ‘moon/forest corner’).

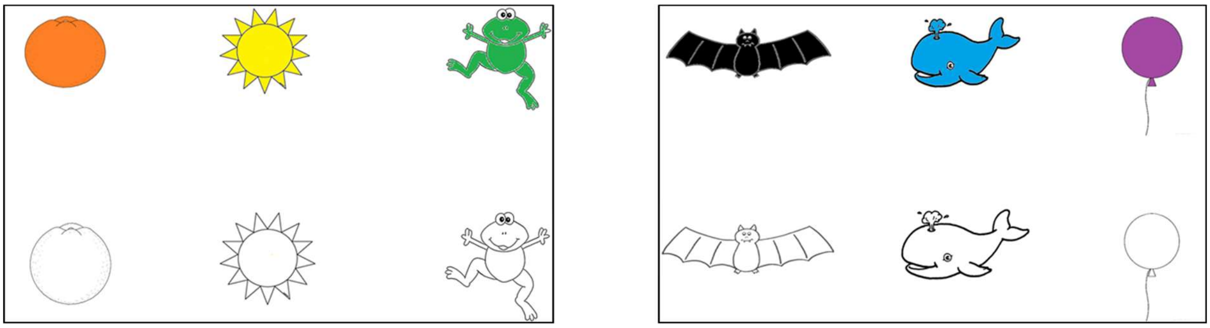
There was a cup holder with 16 coloured pens (two identical sets of eight colours) on a table located at a central point between the two toy kitchens, each set in different contexts in the same room.

Next to the pens on the table was a sheet of paper with eight photographs of the different coloured pens that the children had to select from the cup holder (Appendix F). The use of pictures was two-fold. First, to focus children’s attention on the colour of the pens without actually instructing them to do so. Second, to make the task less reliant on verbal instructions.

The experimenter would bring the child to the table to start the experiment, which was the starting point. There the child was asked, “can you help me find the [insert colour] pen [points to a colour on the sheet]- it is in the cupholder”. Once the child picks up three different coloured pens one by one, the experimenter then says, ‘Now let us hide these pens in the (insert context; moon or forest corner). “I will show you which boxes we will hide them in”. The pens were hidden one at a time: the experimenter would point to the box before telling the child to hide the pen in the box and close the lid. Once all three pens were hidden in their predetermined locations within the hiding apparatus in the first context, the child was returned to the starting point to select another three pens to hide in context two. There were six boxes in each hiding apparatus set within each context, three were empty, and three were for hiding the pens. Once the children made a choice, they opened the box to reveal its contents. We counterbalanced the hiding locations and contexts within and across participants. The rationale for having empty boxes was to control for participants remembering which boxes had pens in them.

After the encoding episodes, there was a 3–5-minute delay during which the experimenter initiated informal conversations with the child before starting the retrieval phase. The child and the experimenter returned to the starting point at the table to begin the retrieval phase. The experimenter presented the participant with a sheet of paper featuring two identical sets of three easily labelled images. While three of the pictures were coloured-in and corresponded to three different coloured pens previously hidden, three remained blank for the child to colour in once the same colour pen was retrieved (see Figure 3.3).

Figure 3.3 *Examples of Colouring sheets used in the Retrieval Phase of What-Where-Which Task*

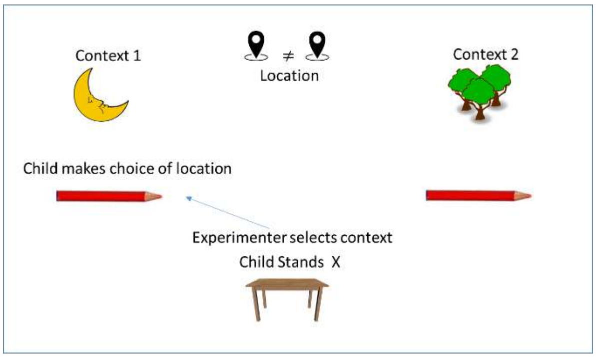


Note. The image shows an example of the colouring sheets used in the retrieval phase (a different colouring sheet was used for each trial; a maximum of two trials) of the what-where-which task. Each colouring sheet featured six images, three of which are coloured-in (which corresponded to the colour of the pen hidden for the tree memory measures [WWWhich, What-Where, and What-Which]), and three remained blank for the child to colour in once the same colour pen was retrieved.

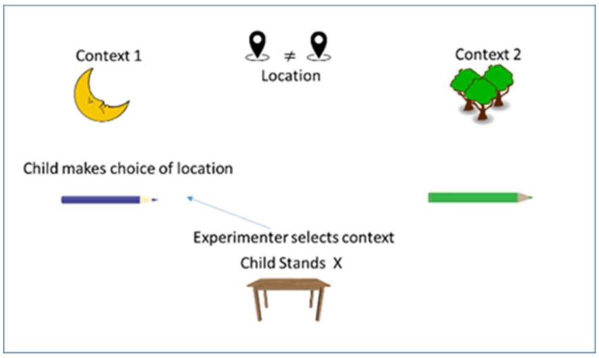
Each hiding episode used a unique set of pictures to test EM for the first hiding episode and another for the second (see Figure 3.3 for example images). Each experimental session was composed of three tests within the same paradigm (EM test, what-where and what-which binding components): (i) What-where Test involved using different coloured pens in different locations in each context - in this scenario, participants were instructed to find a particular coloured pen in a specific context (Figure 3.4b); (ii) What-Which Test involved using different coloured pens in each context but held their Spatial location constant (i.e., by using the same place in each hiding apparatus) – in this scenario participants had to decide whether to look in context one or context two depending on the colour of the pen they needed to find (Figure 3.4c); (iii) The EM Test involved the binding of what-where-which information, so the identity of the pen was held constant (by using the same coloured pen in both contexts), but the location differed (Figure 3.4a). The rationale for directing participants to look in a particular context was to ensure that participants could not achieve correct responses by relying on memory for the item or location alone – they had to integrate the three elements. Thus, demonstrating a coherently bound single representation of the unique combination of object-place-context (what, where, when), not the sum of these elements but their integrations (Clayton & Dickinson, 1998).

When children retrieved a pen from a box, but it was the wrong colour, they left it in the box, and the experimenter moved on to the next colour. Participants received a second opportunity to retrieve the coloured pen at the end of the retrieval session. Likewise, for cases where children went to an incorrect location, but the box was now empty (false hit: either because they retrieved the pen in a previous attempt, or the place never contained a pen – empty), again the child was given a second opportunity to recover the pen. The experimenter recorded whether the child retrieved the items either on the first/second attempt/not at all.

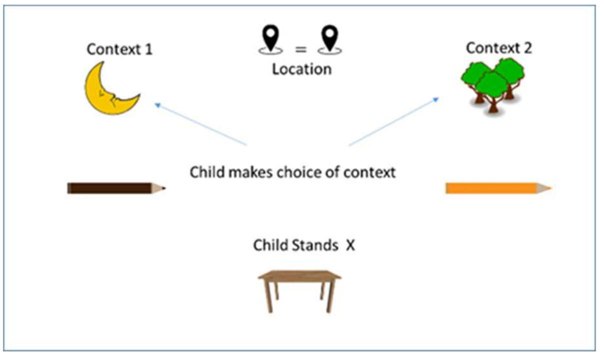
Figure 3.4 *Sample illustration of a Retrieval Session for the Three Memory Measures: WWWhich [EM test], What-Where, What-Which Binding Components*



WWWhich: Object identity same in each context but locations different – child chooses location



What-Where: Object identity + location unique to each context – child chooses location



What-Which: Objects unique to each context but location held same – child chooses context.

Note: The image shows an example of a retrieval session and the object-location-context placements that constituted the three memory measures: EM test [WWWhich], What-Where and What-Which binding components. In each retrieval session, the child retrieves three pens, each of which corresponds to the three memory measures. The starting point within the example retrieval session is noted by X.

[a] EM Test (Fig.4a) involved the binding of What-Where-Which occasion information, so the identity of the pen was held constant by using the same-coloured pen in both contexts, but differing the locations in each context. In this scenario, participants were directed to a specific context and instructed to find a particular-coloured pen (in the example, red pen in Context 1[Moon]).

[b] What-Where (Fig.4b) involved using two unique coloured pens in different locations in each context – in this scenario, participants were directed to a specific context and instructed to find a particular-coloured pen (in the example, blue pen in Context 1 [Moon]).

[c] What-Which (Fig.4c) involved using different coloured pens in each context but holding their Spatial location constant (i.e., by using the same place in each hiding apparatus) – in this scenario, participants had to decide whether to look in context one or context two depending on the colour of the pen they needed to find (in the example; brown or orange pen).

3.2.5 Cognitive Assessment

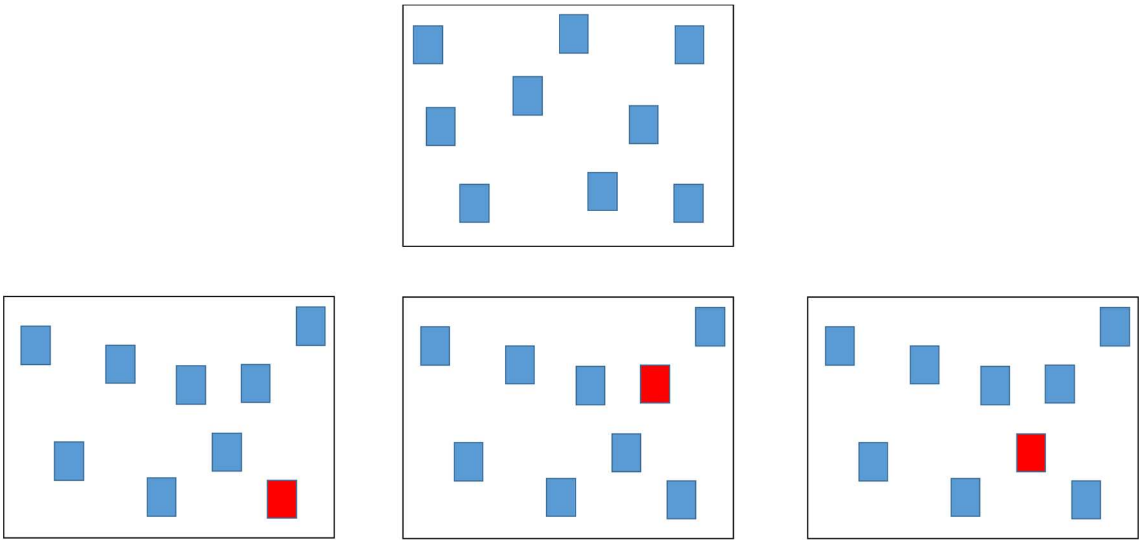
The Wechsler Preschool and Primary Scale of Intelligence – Fourth Edition (WPPSI-IV) (Wechsler, 2012), one of the most widely used measures of intelligence for young children (Raiford & Coalson, 2014), was used to assess cognitive ability. This cognitive assessment is suitable for children aged from 2 years, six months to 7 years, 7 months. The instrument consists of several subtests that include verbal comprehension, perceptual organisation, and processing speed abilities. For the youngest age band (2y6m –3y11m), there are four core subsets (receptive vocabulary, information, block design, and object assembly); for the older age band (4y to 7y3m), the core subsets are information, vocabulary, word reasoning, block design, matrix reasoning, picture concepts and coding. Together these yield composite scores for the two age bands (ages 2:6 to 3:11 years; and 4:0 to 7:7 years), which are composed of different subtests (see Appendix I): Full-scale IQ; Vocabulary Acquisition Index (VAI), as well as specific cognitive abilities such as verbal comprehension, visual-spatial processing, working memory (for 2:6-3:11 years) in addition to fluid reasoning and processing speed for 4:0-7:7 years).

3.2.6 Ancillary tasks

3.2.6 Nonverbal Spatial working memory Assessment

A computerised version of the Corsi-Block Task (Corsi, 1972) was used to assess Nonverbal Spatial working memory. The task was delivered using a computer-based software application on a tablet (Hamilton, 2017). Modelling a traditional Corsi board structure, the layout showed nine blue squares on a white background (see Appendix J for the exact layout and size). The sequence, displayed in red and illustrated in Figure 3.5, starts with two blocks. Once the sequence ended, the participant correctly selected the blocks in the same serial order as shown in the sequence. In total, there were three blocks of trials for each sequence length (from 2 to 9), and to proceed to the next level, the participant needed to get one correct trial. There was no feedback for correct or incorrect responses. The last sequence length with one or no errors defined participants' highest forward Corsi-span. The software recorded the total number of correctly and incorrectly reproduced sequences, first reaction and overall reaction for each block and sequence (this is the delay between the end of the sequence presented on the screen and the first response by the participant), and a Corsi-score.

Figure 3.5 *Example Sequence of the Square Presentation in Corsi-block Task*

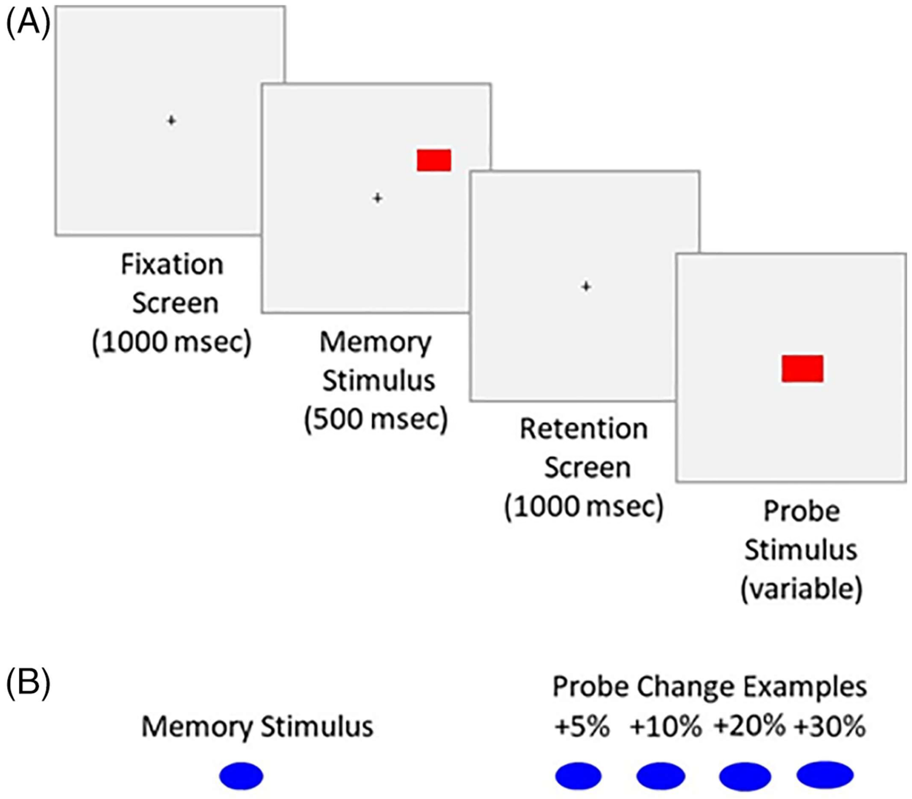


Note. The image shows an example sequence of the square presentation in the Corsi-Block Task. The top image shows the nine blue squares shown at the starting point of the Corsi-Block Test. The bottom images show the sequence of squares that light up as red in a 2D virtual version of the Corsi Block Tapping Test.

3.2.7. Size Just-Noticeable-Difference Task (JND)

Size Just Noticeable Difference (JND) (Hamilton et al., 2018) is a measure of visual short-term memory. In the size JND task, the child decides whether a memory stimulus (red or blue elliptical and rectangular stimuli) presented in the encoding phase is the same size or not as a stimulus presented in the recognition phase (see figure 3.6 for JND protocol). The memory stimulus can appear either on the left or the right, but the probe stimulus is always in the centre. The procedure involves a change trial where the second (probe) stimuli is, for example, 40% smaller than the first (sample) stimuli. Then this is successively decreased (e.g., 30%, 20%, 15%, 10% and 5%) from the original stimuli. A maximum of 24 trials are carried out at each level. Half the trials are change trials, and half have no change. In no trial was the shape change categorical, for example, elliptical to circular, across the 24 trials. The maintenance duration between events was 1s. Administration time: approx.15 mins. This task has been used in typically developing children from 3-4 years up to adulthood.

Figure 3.6 *Example of the Size JND Task Protocol*



Note. The image shows an example of the size JND task protocol (A) shows the temporal sequence, while (B) demonstrates a memory stimulus and alternative probe stimuli that could be used with it (+5 to +30 size variations). The image is taken from Hamilton et al. (2018). Autism Research, Volume: 11, Issue: 11, Pages: 1494-1499.

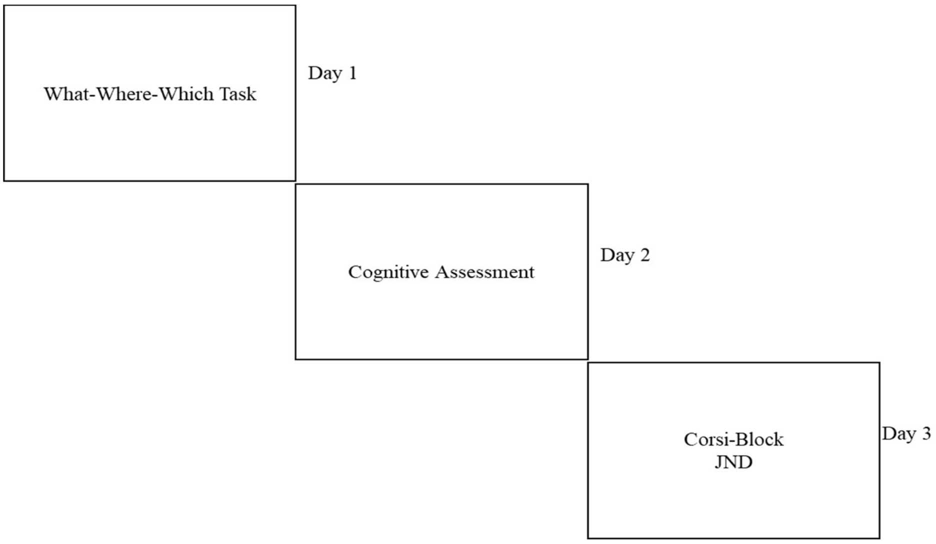
3.2.8 Strength and Difficulties Questionnaire

Parents of non-autistic children completed the short form of the Strength and Difficulties Questionnaire (Goodman, 1997) as a key inclusion criteria. The SDQ is a brief 25-item emotional and behavioural screening questionnaire suitable for children and young people between 2- and 17 years. It comprises five scales that measure emotional symptoms, conduct problems, hyperactivity/inattention, peer relationship problems and prosocial behaviours. It generates a total difficulties score (from 0 to 40) by summing the scales' scores except for the prosocial behaviour scale. Participants were included if they scored on or below a cut-off score of 11, which indicates functioning within the 'typical' range.

3.2.9 Procedure

The study took place over three consecutive days, thereby minimising the test load burden on children (see Figure 3.7 for a schematic of experiment order). All tasks were not given to all age groups for practical reasons. Three-year-old children were not administered the Corsi-block task. Reason being 3-year-old children attended nursery two days a week and not always consecutively. As a result, we prioritised testing on the WWWhich task (Day 1), cognitive assessment and JND (Day 2). The JND task was a relatively easy and short task to administer and did not demand a significant amount of time for conducting.

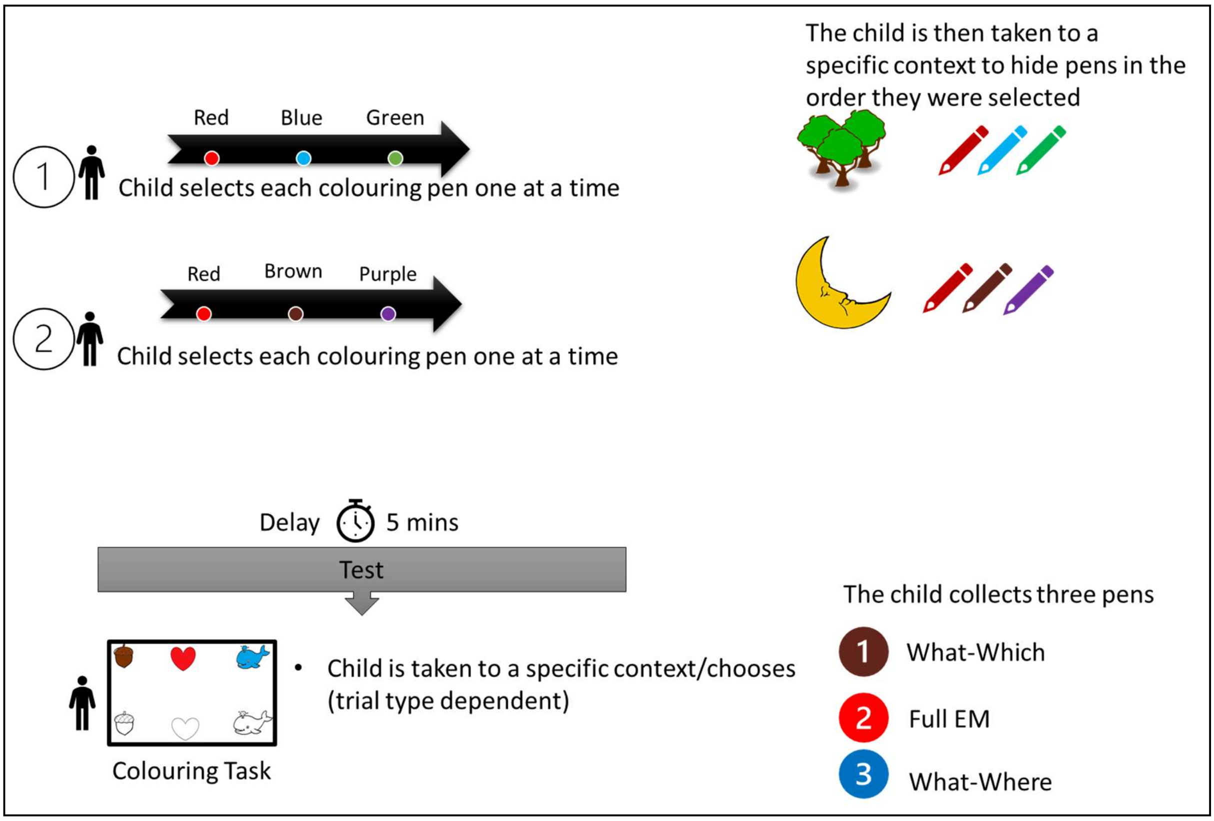
Figure 3.7 *Schematic Diagram of Experimental Schedule*



Note. The image shows a schematic diagram of the experimental schedule. The tasks featured here are shown in the order in which they were administered each day. Children completed the what-where-which task on Day one; Day two, the cognitive assessment; Day 3, the Corsi-block and then the Just-noticeable-difference task (JND).

All children were tested individually in a quiet room in their school or a laboratory at Durham University. The three memory measures (WWW, WW and Wwhich) were administered in a pseudorandomised order and were administered in counterbalanced order across participants. Children first undertook the first encoding session of the What-where-which Test (counterbalanced between subjects). On the first day, participants completed the What-Where-Which task test across two encodings and two retrieval sessions (see figure 3.8 for an example of the encoding and retrieval for the EM test, Object-place test [What-where] and the object-temporal context Test [What-Which]).

Figure 3.8 *Implementation of EM task with children*



Note. The image shows an example of implementing a trial for full EM assessment and its bound components (what-which and what-where). In the example, there are two encoding phases. In phase 1, the experimenter points to a picture of the red pen, and the child picks it up: this is repeated until the child has picked up all three colouring pens. Then, the child is taken to a specific context (i.e., the ‘Forest’ context in the example) and is shown where to hide the pens. The pens were always hidden one at a time in the order they were selected. After the three pens had been placed, another three pens (e.g., red, brown, purple) were hidden in the second context (i.e., ‘Moon’ context in the example) in the same manner. After encoding, there was a 5-minute interval. Finally, during the retrieval phase, the child is shown a colouring sheet with two sets of three images (one set for reference and one set blank for the child to colour in). Depending on the trial type, at retrieval, the experimenter takes the child to a specific context (applicable for full EM and what-where trials) or is taken to a central position and asked to choose a ‘corner’ (forest / Moon). At the end of retrieval, the child sat down at a table to complete the colouring task. Each child completes two trials, run consecutively. In each instance, different colouring pens and colouring sheets are used.

3.2.10 Analysis

Assumptions of normality; the dependent variable for the main episodic task has a binary outcome that is not normally distributed. As a result, nonparametric tests were used to analyse the data. All statistical comparisons were two-tailed (unless otherwise specified), using $p < .05$ as the level of significance. Analyses were undertaken through SPSS and the JASP 0.13.1 (2020). Generalised Estimating Equations (GEE) were used to analyse memory performance as it allows for the analysis of repeated binary measurements of accuracy status. We selected an exchangeable working correlation matrix (this matrix structure is used for measurements from the same individual with no time dependence), specifying a binomial distribution with a logistic link. Because two models were tested, we considered *p*-values less than 0.025 ($\alpha Bonf = 0.05/2$) to be significant.

Where possible, we reported Bayes factors (BF_{10}) expressing the evidence for the alternative H1 over the null H0 (i.e., values larger than one favour H1 [see Table 3.2 for Bayes Factor classifications and interpretations]). Bayes Factors for the outcomes of the main episodic and what-where/which bindings task, which consists of binary data (correct or not), were calculated using an online calculator designed specifically for binary data and described in Mazurek et al. (2015). The Matlab code and an executable of the calculator itself can be downloaded from http://www.jennyreadresearch.com/research/matlab-code/bayes-factors-for-binomial-data/.

Table 3.2 *Bayes Factor Classifications and Interpretations (Adapted from van Doorn et al., (2021).*

Bayes Factor	**Interpretation**
10-30	Strong Evidence for H_1
3-10	Moderate Evidence for H_1
1	Weak Evidence for H_1 and H_0
1/3 – 1	Weak Evidence for H_0
1/10 – 1/3	Moderate Evidence for H_0
1/30 -1/10	Strong Evidence for H_0

Note. The table shows the Bayes Factor classifications and their interpretations relating to the strength of evidence they provide for H_1 and H_0 depending on the direction in which the Bayes Factor deviates from 1. Adapted from The JASP Guidelines for Conducting and Reporting a Bayesian Analysis (van Doorn et al., 2021).

To differentiate above-chance performance, we calculated the hypothesised probabilities for each test type (i.e., EM test, What-Where test, What-Which test) based on the three possible outcomes (0, 1, 2 correct) and the available hiding places (six locations) or context (one vs two) depending on the test. Due to violations of assumptions for the chi-square test for goodness of fit (1. That 80% of the cells have an expected frequency of greater than five; and 2. That no cell has an observed frequency of 0), it was necessary to recombine the three outcomes into two (i.e., no trials correct, and 1/more trials correct). Therefore, the probability of locating an item in the EM test and What-Where Test was specified as *Pr* = 0.66 (no trials correct) and *Pr* = 0.33 (one or more trials correct), respectively. The hypothesised probability for getting one or more trials correct on the what-which Test was specified as *Pr* = 0.75. As some participants attempted more than one retrieval (i.e., they opened a second box as the first attempt was incorrect), only the first response of each trial type (EM, what-where, what-which) was analysed (except when analysing errors).

Errors were identified as object errors and spatial errors. An object error would be incorrectly choosing a location where an item was present, but it was not the correct item. A spatial error would be incorrectly selecting a place where there never was a pen (i.e., an empty box). We also noted whether participants made revisit errors (visiting the exact location twice).

3.3 Results

Of the 51 children, all could correctly identify the colour swatches in the colouring task and complete the familiarisation task without repetition. All children revealed interest in the task at hand.

3.3.1 Temporal Order

We addressed the possibility that accurately locating items on the three memory measures (WWW, What-Where, What-Which) depended upon how recently the information was encoded (i.e., Time 1 vs Time 2). Results of the exact McNemar Test determined that there were no significant changes in accuracy (correct/incorrect responses) between Time 1 and Time 2 on all three trial types (WWW, What-Where, What-Which), all *p* values > .05 (see Table 3.3). Hence, the data collected from Time 1 and Time 2 are considered together.

3.3.2 Performance in relation to chance

First, we converted the accuracy data (getting none, one or two trials correct) into two discrete possible outcomes (getting no trials correct versus one or more correct). Children's performance ($N = 51$) was analysed relative to chance levels using a one-tailed binomial test. Results showed that the proportion of children recalling accurately was significantly above what one might expect by chance alone on all three memory measures (all p values <.001; chance set at .33 for WWWhich, What-Where; and .75 for What-Which) (see Table 3.4). Two separate binomial tests were also undertaken for each age group (3-4-year-olds and 5-6-year-olds) to clarify performance was not driven by older children. Results showed (see Figure 3.9) that for WWWhich and What-where memory measures, both age groups recalled more than would be expected by chance (all p values < .002). For What-Which (chance = .75), only the older children (5–6-year-olds) recalled significantly more (100%, p <.001). The performance of the 3-4-year-olds did not differ from chance (82.4%, p = .353, BF_{10} = .815). Therefore, in instances where events were recalled, WWWhich and WW trials were the only memory measures for whom their recall was reliably greater than chance for children of all ages.

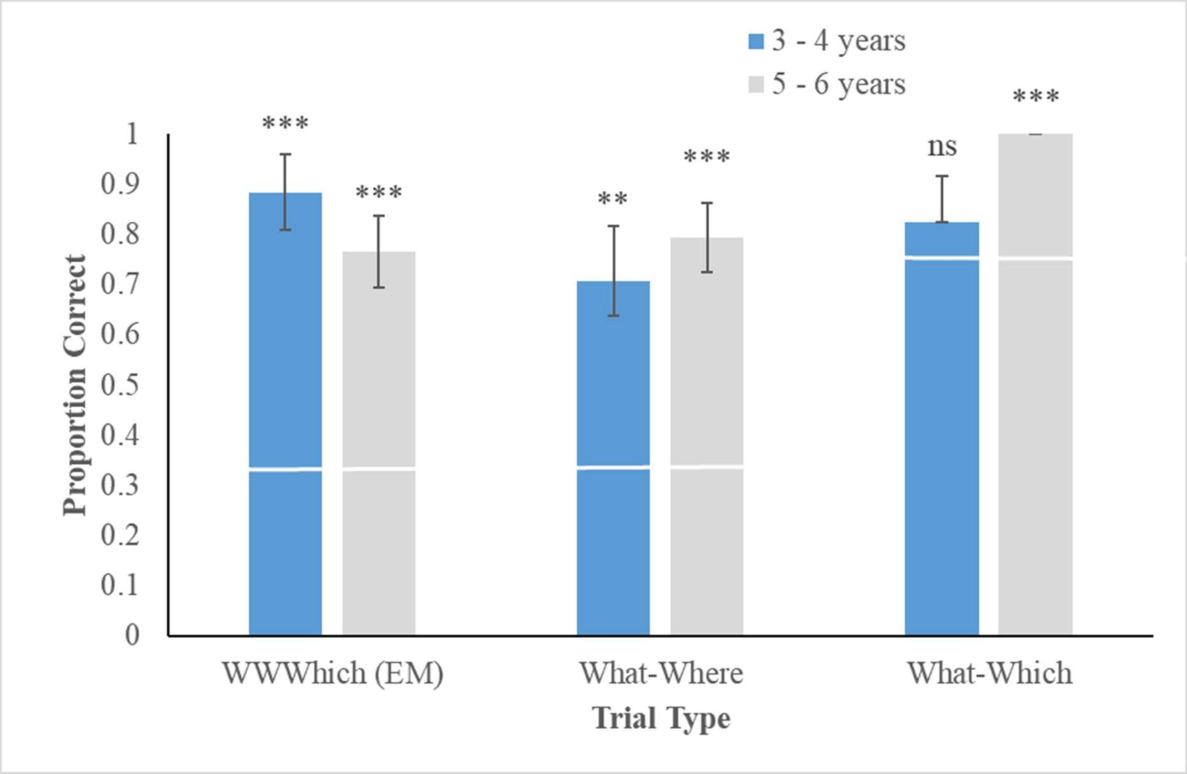
Table 3.3 *Binomial test Assessing Performance Against Chance for all Trial Types*

Trial Type	**Accuracy**		**Proportion**		***p***
	Incorrect	Correct	Incorrect	Correct	
WWW	10	41	.196	.804	<.001

What-Where	12	39	.235	.765	<.001
What-Which	3	48	.059	.941	<.001

Note. One-Tailed Binomial test of children's ($N = 51$) accuracy (getting one or more trials correct versus incorrect) on all three memory measures. Chance set at 33% for WWWhich (full EM) and What-Where tests and 75% for the What-which test.

Figure 3.9 *Memory performance (across two trials) in relation to chance levels as a function of trial type and age group*



Note. The figure displays the proportion of successes (i.e., correct responses, defined as getting at least one/more trials correct) by children ($N = 51$) as a function of test type (WWWhich [full EM], What-Where, and What-Which) and age group (3-4 years, $n = 17$; 5-6 years, $n = 34$). Ns indicate that the results are not statistically significant. White lines represent chance as proportions, set at .33 for WWWhich [full EM] and What-Where tests and .75 for the What-Which test. Asterisks indicate results significantly above the chance level, **significant at $p \leq .01$, *** at $p \leq .001$. Both age groups performed significantly better than chance for the WWWhich and What-Where memory measures. The 5-6-year-olds performed significantly better than chance for the What-Which binding component, while the 3-4-year-olds did not differ from chance.

3.3.3 Overall Memory performance (WWWhich Memory and its bindings)

Table 3.5 illustrates the mean accuracy across the two trials (getting none, one or two trials correct) for the WWWhich [full EM] test and its binding components as a function of age group.

Table 3.4 *Descriptive Statistics of EM and its Components by Age Group in Children*

	3-4 years (N=17)		*5-years (N=16)*		*6-years (N=18)*		*Total (N=51)*	
	M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
WWWhich	1.00	0.50	1.31	0.70	0.50	0.62	0.92	0.69
WW	0.82	0.64	1.25	0.86	1.06	0.64	1.04	0.72
WWhich	1.41	0.80	1.69	0.48	1.72	0.46	1.61	0.60

Note. The table illustrates the mean accuracy across the two trials (getting none, one or two trials correct) for the full EM test (WWWhich) and its binding components (WW, WWhich) as a function of age group (3-4, 5, and 6-years). See Appendix N for raw data tables for performance on the WWWhich task and for the ancillary tasks.

To examine overall memory performance and whether it differed depending on the memory assessed (Trial Type: WWWhich, WW, WWhich) and age, we first grouped children into three groups: 3-4-year-olds (*n* = 17; due to the limited number of 3-year-olds [n = 6]), 5-year-olds (*n* = 16), 6-year-olds (*n* = 18). A Generalised estimating equation analysis was then conducted using accuracy (correct/incorrect) as the dependent variable, trial type (WWW, What-Where, What-Which) and trial number (1 and 2) as within-subjects factors and trial type and age group as predictors. The GEE procedure models the lowest value, here, accuracy (0 = incorrect) as the reference category, so what is modelled is the probability of it being the highest value 1 (i.e., correct) in comparison with this reference category. The GEE evaluation (Table 3.6) revealed that performance differed significantly depending on the trial type (Wald X^2 = 31.925, p <.001). Age-group (Wald X^2 = 6.367, *p* = .041 [a_{Bonf} = .025) and trial number (Wald X^2 = .501, p = .479 were not significant (see Figure 3.10). There was, however, a significant two-way interaction between age and trial type (Wald X^2 = 12.966, p = .011). The GEE post hoc analyses using pairwise comparisons revealed that for the full EM test (WWWhich) the younger participants (3–4-year-olds, and 5-year-olds) both outperformed the oldest children (6-years) (3-4 years *M* diff = .25, p = .007; 5-years *M* diff = .41, p <.001). Whereas for all other memory measures (WW and WWhich) children from all age groups were equally accurate (all p-values >.05).

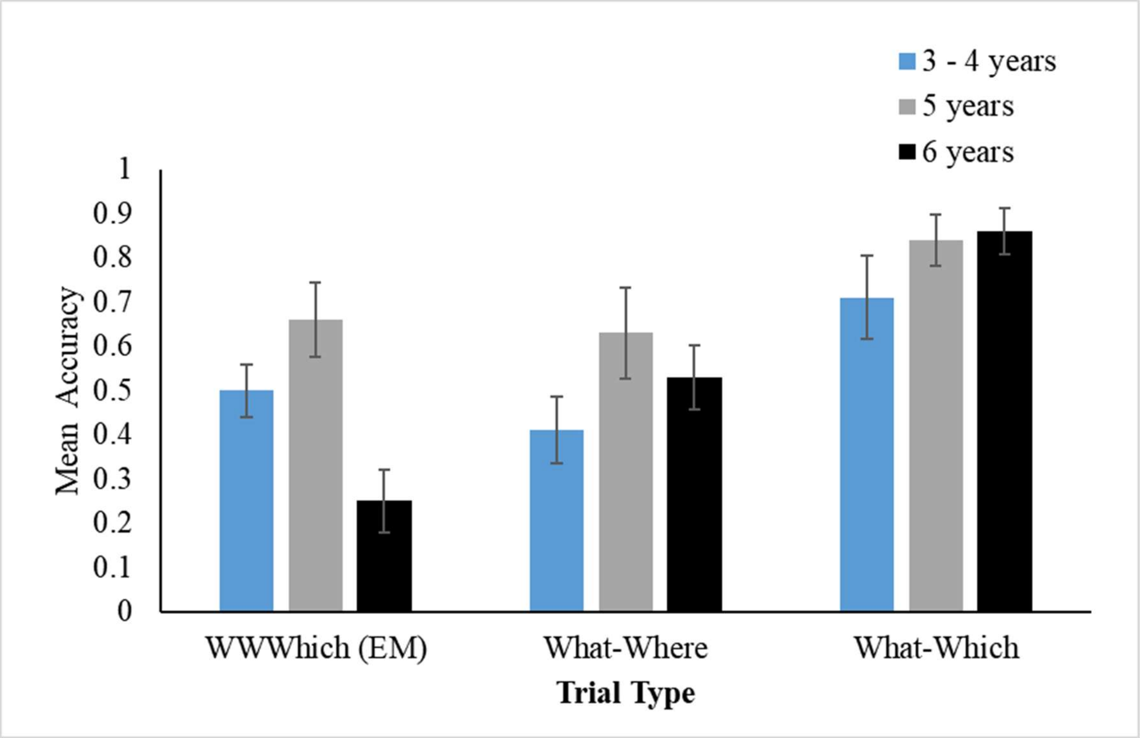
Table 3.5 *Analysis of the GEE parameter estimates, with Success as the outcome variable, and trial type and age, and the interaction between Trial Type and Age as explanatory variables*

Parameter	*B*	*SE*	*Wald X2*	*p*	*Exp(B)*
Trial Type					
WWWhich	- 2.929	.4825	36.841	<.001	.053
WW	-1.716	.4658	13.575	<.001	.180
WWHICH	0^a				1
Age					

3-4 years	-0.950	.6310	2.268	.132	.387
5-years	-0.138	.6235	0.049	.824	.871
6-years	0^a				1
Trial Type * Age					
WWWhich * 3-4-years	2.051	.7010	8.563	.003	7.778
WWWhich * 5-years	1.887	.7302	6.680	.010	6.601
WWWhich * 6-years	0^a				1
WW * 3-4-years	.481	.7120	.457	.499	1.618
WW * 5-years	.539	.7682	.492	.483	1.714
WW * 6-years	0^a				1
WWhich * 3-4-years	0^a				1
WWhich * 5-years	0^a				1
WWhich * 6-years	0^a				1

Note. This table demonstrates the parameter estimates from the GEE analysis examining the main effects (and interaction) of Trial Type (WWWhich, What-Where, What-Which) and Age-Group (3-4, 5- and 6-years) of mean memory accuracy (correct/incorrect) The GEE procedure models the lowest value, here, accuracy (0 = incorrect) as the reference category, so what is modelled is the probability of it being the highest value 1 (i.e., correct) in comparison with this reference category.

Figure 3.10 *Mean Accuracy on the WWW task (and binding combinations) as a function of age*



Note. The figure shows the results from the GEE analysis estimating the mean probability of a correct response given trial type, trial number, and age group. Mean and standard errors of the mean were computed with Generalized Estimating Equations (GEE) models. Error bars represent the standard error of the mean. Results showed that performance differed significantly depending on the trial type (Wald X^2 = 31.925, p <.001). Age-group (Wald X^2 = 6.367, p = .041 [*aBonf* = .025) and trial number (Wald X^2 = .501, p = .479 were not significant. There was, however, a significant two-way interaction between age and trial type (Wald X^2 = 12.966, p = .011). The GEE post hoc analysis showed that for the WWWhich test, younger participants (3-4 and 5-year-olds) outperformed the oldest children (6-year-olds) (p = .007 and p < .001, respectively), while for other memory measures, all age groups performed similarly (all p > .05).

3.3.4 Influence of Visuospatial Working Memory and Visual STM on Memory Performance

We were also interested in whether visuospatial working memory and visual STM affect performance. To investigate this, an additional GEE analysis was made, adding scores from the Corsi-Block FS (visuospatial WM) and size JND task (visual STM) as covariates ($N = 45$ as only children above the age of 4 years completed all ancillary tasks). We added three interaction terms (Trial Type × Corsi Block FS, size JND, and AgeGroup [4,5,6 years). Nonsignificant interactions were removed in a stepwise manner.

The GEE analysis revealed no main effects of trial type (Wald $X^2 = 6.629$, p =.036 [$a_{Bonf} = .025$]) or Age Group (4,5,6 years) (Wald X^2 6.629, p=.036 [$a_{Bonf} = .025$]), trial order (Wald $X^2 = 1.273$, $p = .259$), Corsi-Block FS (Wald $X^2 = 1.278$, p = .258) or Size JND (Wald $X^2 = .077$, p = .782). There was, however, a significant interaction between Trial Type and Age Group (Wald $X^2 = 14.061$, p =.007), indicating that children's responses differed depending on the trial type and their age. Post-hoc analysis of the parameter estimates showed that 5-year-olds were significantly more likely to recall accurately on the WWWhich task (Wald $X^2 = 6.110$, p = .013) than 6-year-olds (see Table 3.7). Indeed, 7.028 times more likely.

Table 3.6 *Analysis of the GEE parameter estimates, with Success as the outcome variable, trial type and Age group as predictors, and visuospatial working memory and visual short-term memory as covariates (N = 45)*

Parameter	*B*	*SE*	*Wald X2*	*p*	*Exp(B)*
Trial Type					
WWWhich	-2.962	.9435	9.857	.002	0.052
WW	-.176	.8566	.042	.837	.838
WWhich	0^a				1
Age Group					
4-years	-.463	.6857	.456	.499	.629
5-years	.094	.6456	.021	.884	1.099
6-years	0^a				1
Corsi Block FS	.476	.3389	1.975	.160	1.610
Size JND	.023	.0836	.077	.782	1.023

Trial Type * Age Group					
WWWhich * 4-years	1.572	.8565	3.369	.066	4.817
WWWhich * 5-years	1.950	.7888	6.110	.013	7.028
WWWhich * 6-years	0[a]				1
WW * 4-years	-.187	.7082	.070	.792	.830
WW * 5-years	.156	.8167	.037	.848	1.169
WW * 6-years	0[a]				1
Trial Type * Corsi FS					
WWWhich * CorsiFS	-.052	.4048	.017	.898	.949
WW * CorsiFS	-.783	.3860	4.115	.042	.457
WWhich * CorsiFS	0[a]				1

Note. This table demonstrates the parameter estimates from the GEE analysis for the effects of Trial Type on memory accuracy (correct/incorrect) when accounting for individual differences in visuospatial working memory and visual STM (measured using the Corsi-Block Task and Size-JND Task, respectively). The procedure models the lowest value, here, accuracy (0 = incorrect) as the reference category, so what is modelled is the probability of it being the highest value 1 (i.e., correct) in comparison with this reference category. This includes data for *N* = 45 children (4-6 years).

3.3.5 Binding of What-Where and What-Which on WWWhich

To test whether performance on the WWWhich task was predicted by memory performance on the what-where and what-which task across the two trials. We then performed a GZLM analysis using performance on the WWWhich task (None, One, or Both Trials Correct) as the dependent variable (with a fixed value of two trials) and Age group (3-4, 5- and 6 years) as a predictor and what-where and what-which entered as covariates. Non-significant interactions between predictors and covariates were removed from the analysis in a stepwise manner, starting with the highest interactions until none remained. Results showed that performance on the WWWhich task was independent of children’s accuracy on

What-Where (Wald X^2 = .0004, p = .983) and what-which tasks (Wald X^2 = .526, p = .468) but was dependent upon age (Wald X^2 = 11.010, p = .004). with both 3-4-year-olds and 5-year-olds outperforming 6-year-olds (see parameter estimates in Table 3.8).

Table 3.7 *Analysis of the GLZM parameter estimates, with WWWhich Success as the outcome variable, What-Where and What-Which and Age as predictors (N = 51)*

Parameter	*B*	*SE*	*Wald X2*	*p*	*Exp(B)*
Age Group					
3-4 years	1.184	.5344	4.907	.027	3.267
5-years	1.759	.5400	10.607	.001	5.805
6-years	0^a				1
What-Where	.006	.3059	.0004	.983	1.007
What-Which	.260	.3590	.526	.468	1.297
Scale	0^a				1

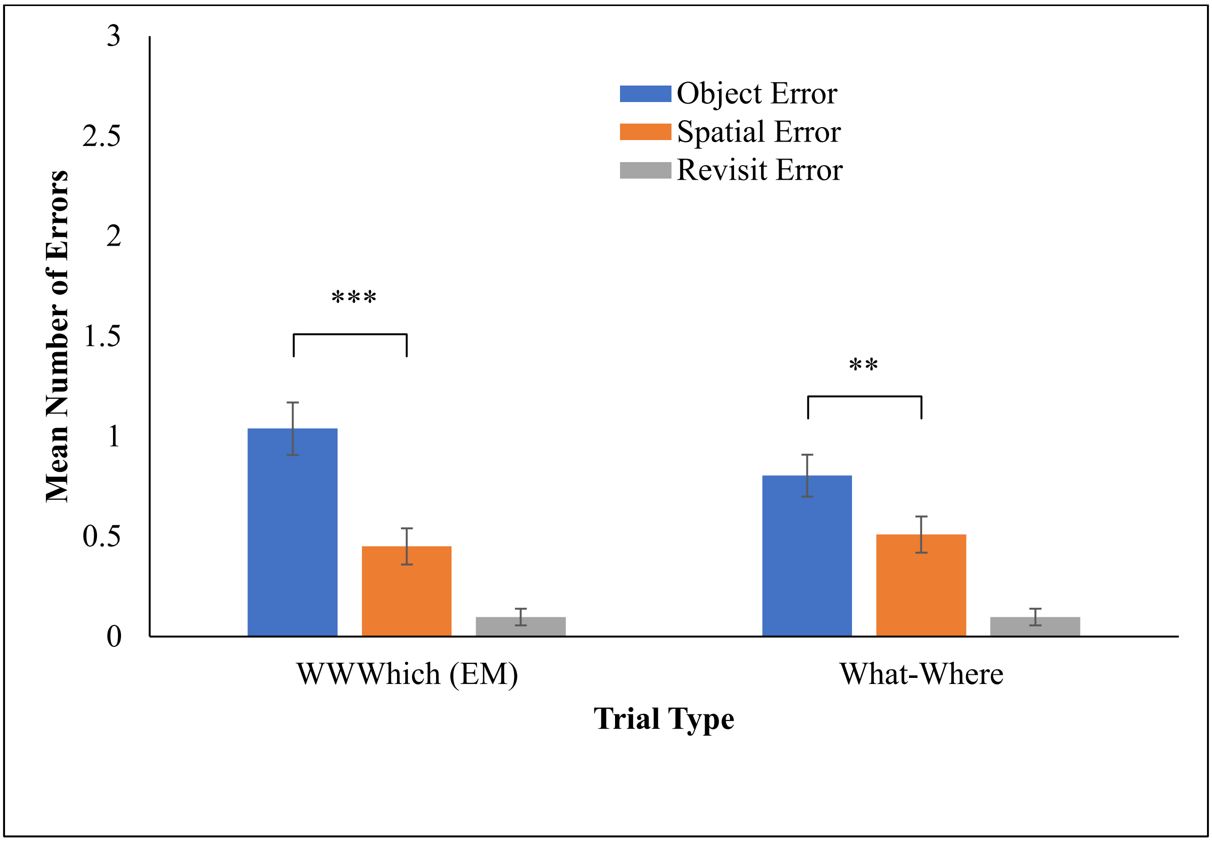
Note. The table shows the GZLM parameter estimates examining WWWhich success as the outcome variable, Age group (3-4, 5-, and 6 years) as predictors and What-Where and What-Which as covariates (*N* = 51).

3.3.6 Types of Errors on WWW Test

To determine why an error occurred, we examined whether incorrect choices of the boxes that (1) contained a pen (object error) exceeded choices of those that (2) never contained pens (spatial error). We also noted whether participants made revisit errors (visiting the exact location twice).

Wilcoxon signed ranks test revealed that children made significantly more object incorrect choices (*M* = 1.039, *SE* = .131) than completely incorrect choices (*M* = .451, *SE* = .09*)* for the WWWhich test, *W* = 474, p <.001; one-tailed (see Figure 3.11). This was also the case for the What-Where test; significantly more object incorrect choices (*M* = .804, *SE* = .105) than completely incorrect choices (*M* = .51, *SE* = .09*), W* = 258, *p* = .014; one-tailed.

Figure 3.11 *Comparison of Errors as a Function of Trial Type*



Note. This figure shows the mean number of errors made by 51 children on the WWWhich and What-Where binding combinatios, by error type (object, spatial and revisit). The error bars represent the standard error of the mean. The Wilcoxon signed-rank test revealed that for both the WWWhich and What-Where binding combinations, children made significantly more object incorrect choices than completely incorrect choices (spatial errors), with asterisks indicating significance levels (** p ≤0.01, *** p ≤0.001).

Object error = an item was present in the box, but it was not the correct item.

Spatial error = selecting a box where no item was ever present.

3.4 Discussion

The present study investigated whether the novel methodology developed with adults in chapter 2 to assess episodic memory could be conducted with children (3 to 6 years). In the current task, there were no requirements to verbalise specific memories to an experimenter explicitly. Instead, children searched for a hidden colouring pen as part of a colouring task to demonstrate memory for the three unique events (what-where-which occasion, what-where and what which occasion – all within the same paradigm) to determine overall accuracy across two test trials.

There are three main findings from this study. Firstly, the WWWhich memory task is a valid measure of episodic memory in children, as their performance was significantly above chance levels on the full episodic version of this task (binding of object-place-context). Overall, children of all ages demonstrated memory for bound information *(what-where* and *what-which* components of a hiding event, though accuracy on the latter, were driven by older children's accuracy). Still, they experienced greater difficulty in recalling memory for the bound *what-where-which* EM test. However, even when children made incorrect choices, there was still a memory for details of an event evidenced by not making wholly wrong choices (i.e., by not selecting an empty container). These findings support the hypothesis laid out in the introduction, as even our youngest children are adept at recalling episodic events within a nonverbal WWWhich paradigm.

Secondly, in line with recent research suggesting that EM is underpinned by earlier developments in the binding of where and when in memory (Mastrogiuseppe et al., 2019), we hypothesised that EM would be underpinned by binding item-to-location (what-where) and item-to-temporal context (what-which). This hypothesis was not supported. While episodic memory is composed of several distinct components (what-where-which occasion), its success was not dependent on the associative process of binding '*what-where*' and '*what-which*' in our sample of children between 3 and 6 years (but see Mastrogiuseppe et al., 2019) but it was dependent upon age with 3-4-year-olds 3.267 times more likely, and 5-year olds 5.805 times more likely than 6-year olds to recall correctly. Recently, Mastrogiuseppe et al. (2019) took a different approach to studying episodic memory (i.e., what-where-when) within a nonverbal object-placement task and found developmental changes in where-when binding to the extent that it preceded and was critical to full EM (what + where + when). The task (WWW task) with 2-8-year-olds comprised three phases: the demonstration phase, where a child observes the experimenter hide three objects, the encoding phase, where the child re-enacts the observed actions, then following a delay (3-mins delay involving a verbal interference task) the child re-enacts their *own* previous actions (retrieval phase). To assess full EM, children's accuracy between the encoding and retrieval phase was calculated, providing a single assessment of correctly recalled what, where and when components of an event and their combination (EM)—in contrast, recovering hidden items in the current study that were bound to spatial locations or to a specific temporal context made it impossible to examine discrete elements such as spatial and temporal combinations. Take, for example, the object-location test in the current study. In this scenario, participants are taken to a specific temporal context (the background on the hiding apparatus in this case) to recover a hidden object (e.g., red pen) which is unique to that context. Should the participant choose an incorrect location, we cannot suppose that the child made this error based on a failure to recall the item or its location because the test of memory requires both, rather, we assume the two elements were not sufficiently bound. Consequently, decomposing full EM (or its bindings) to manipulate specific combinations is challenging and amplifies a direct comparison problematic. We know from previous research (Newcombe et al., 2014) that the binding of a toy to the box containing it and to the room in which the box was located is possible in the second year of life. This may explain why we could not capture age-related differences in WWWhich binding because children are already able to achieve this before the age of three years. It may also be the case that tasks using when (WWW tasks, rather than context as a temporal identifier in WWWhich occasion) depend on binding space-time. Hence, better binding ability should predict better episodic ability. Although we found an age-related improvement in episodic ability, there was no evidence of an age-related improvement in binding components. This makes differentiating between the hypothesis that children will show age-related improvements in WWWhich and What-which binding abilities only partially supported.

Thirdly, we hypothesised that visuospatial WM and visual STM would support memory recall on the EM task (and its binding components [what-where, what-which]). Instead, we found that the ability to fully bind the *what, where* and *which* occasion components of an event was predicted by age even after accounting for developmental differences in WM and STM, suggesting that in neurotypical development, memory success on the EM task is not explained by improvements in visuospatial WM or visual STM but by age-related changes in long-term EM. Specifically, accounting for visual WM and visual STM, we found EM to be present in 3-4-year-olds, showing robust gains by 5 years but with 6-year-olds experiencing a reduction in accuracy, performing less than 3-4-year-olds in this paradigm. This supports the findings of Newcombe et al. (2014) that EM follows a protracted developmental course, reaching maturity at 5-year and supports our hypothesis that episodic memory will improve gradually with age. The discrepancy between early success in EM in 3-4-year-olds and a decline in 6-year-olds may indicate a temporary regression in this paradigm. For example, many studies have shown robust age differences between 4- and 6-year-old children, with 6-year-olds performing better than 4-year-olds on tasks that source memory (i.e., the ability to recall the source of remembered information) (Drummey & Newcombe, 2002), relational memory (the ability to remember associations between objects/events) (Lloyd et al., 2009; Sluzenski et al., 2006), as well as their ability to recall contextual details (i.e., the spatial/contextual, or temporal circumstances associated with these stimuli (Bauer et al., 2012; Newcombe et al., 2014; Riggins et al., 2018; Riggins & Rollins, 2015). Equally, it is also important to note that developmental improvements in memory do not always follow a linear trajectory where performance increases with age (e.g., Riggins, 2014). It has been argued that the hallmark of the developmental process is periods of disorganisation and behavioural regression (Marcovitch & Lewkowicz, 2004). Overall, our results show continuous developmental growth in EM for up to 5 years. The naturalistic and interactive design of the paradigm likely increased the saliency of the task, coupled with its nonverbal assessment, making it easier for younger children to perform well over the short retention interval of 5-mins between encoding and retrieval. It is possible that age-related differences following linear improvements might be detected at longer intervals.

Most empirical paradigms designed to examine episodic memory are dominated by verbal paradigms such as interview-based assessments (open-ended, structured) and free recall tasks where participants are requested to retrieve a list of words. Evidence from nonverbal paradigms that examine memory for what-where-when/which (e.g., Hayne & Imuta, 2011; Newcombe et al., 2014; Russell et al., 2011) suggest that even the youngest children are capable of demonstrating episodic memories when providing nonverbal evidence of memory (but see Cuevas et al., 2015). Hayne and Imuta (2011) used behavioural and verbal recall measures of performance in a hide-and-seek version of the WWW task in children's homes. The procedure involved 3- and 4-year-old children hiding toys in three disparate locations in their own homes. After a 5-minute retention interval, the child was asked to verbally recall the WWW elements of a hiding event (i.e., what toys were hidden, where the toys were hidden, and the order in which the rooms were visited). They were allowed to recall the same information behaviourally except the 'what' component, giving nonverbal evidence of memory. Findings showed an improvement in retrieval for behavioural recall in 3-4-year-old children, suggesting that by reducing language confounds, children can form episodic memories before its hypothesised emergence at 4- to 5 years of age. Arguably, the improvement in retrieval (for behavioural recall) could be explained by having first verbally recalled the WWW elements – rendering memories more accessible on the subsequent behavioural trial, a somewhat refreshing of their memory. Nevertheless, the results illustrate that our nonverbal approach provides further evidence to support the notion that we might be underestimating young children's episodic abilities simply due to methodological constraints, given that our youngest children outperformed 6-year-olds.

3.5 Conclusions

In conclusion, the findings of this novel research highlight that the WWWhich memory task is a valid measure of episodic memory in children. Episodic abilities were present in 3-4-year-old children (reaching maturity at 5 years), with our youngest children outperforming 6-year-olds. This suggests that this paradigm may be especially effective for younger children. Notably, the age-related changes in episodic memory were not underpinned by improvements in visuospatial working memory or visual short-term memory, highlighting advances in long-term memory. Furthermore, the ability to recall specific past events located in a particular context and place is not supported by a separate ability to find *what-where* or *what-which* past events, suggesting it is bound holistically by the *simultaneous* integration of the what-where-which elements. This somewhat contrasts with other research, which has found that the binding of spatial and temporal precedes EM and is what allows for successful EM. There may be multiple reasons for such a discrepancy, such as methodological differences. Further research is needed to clarify whether this is a possible explanation. In sum, this novel nonverbal paradigm provides a tool for assessing episodic memory in children without relying on the children's language ability. This opens an opportunity to use this paradigm with younger children and those with neurodevelopmental conditions such as autism, allowing us to refine our knowledge of the development of episodic memory in these groups.

4 Chapter 4– Exploring EM in Autistic Children

Having identified the need to remove language confounds from tests of episodic memory in children – see Chapter 3, this chapter explores whether a behavioural and nonverbal measure of episodic memory can be used in autism to understand the memory profile of autistic children when potential language confounds associated with the task are removed. In keeping with the current consensus on which terms should be used in autism research (Kenny et al., 2016; Pellicano & Stears, 2011), we use "autistic/autistic children" terminology throughout this thesis.

4.1 Introduction

Episodic memory is the ability to encode, store and recall personally experienced events associated with a specific time and place. Despite four decades of research, we are still left with unexplained questions regarding how episodic memory emerges in typical development from the rudimentary forms observed in infancy to the sophisticated adult episodic system. The picture is similar in autism; the profile of episodic memory across the lifespan is poorly understood. This mainly stems from a lack of longitudinal studies that can track age-related changes in episodic memory skills at different life stages. There is also a relative lack of cross-sectional research involving autistic children yet to reach adolescence, so little is known about episodic skills in autism in early childhood or, for that matter, those entering late adulthood. Hence, with the focus on later development, it may be misleading to assume that younger autistic children are disproportionately impaired in the same manner. The possibility, therefore, that the episodic memory-related difficulties faced by autistic children may be different since they are still developing – thus merits attention.

4.2 Episodic Memory in Autism

Autism is a lifelong neurodevelopmental condition associated with considerable difficulties in social communication and restricted behaviours (DSM-5 diagnostic criteria; American Psychiatric Association, 2013). It is a remarkably heterogeneous condition resulting in a spectrum of neurodiversity that covers an enormous range of abilities and co-occurring conditions and varies in the level of support an individual needs. In conjunction, but not forming part of the diagnostic criteria, autism is also associated with a series of global difficulties in memory (described in Chapter 1), particularly episodic memory (for review, see Cooper & Simons, 2019; and for meta-analyses, see Desaunay et al., 2020). This contrasts with the relative preservation of semantic memory (i.e., factual knowledge) (for review, see Boucher et al., 2012). As such, an Autistic child might be able to identify over 100 world flags but experience difficulty telling one thing they did (or liked) during a school day.

As discussed in Chapter 1, there is a relative paucity of research directly examining episodic memory in autistic children under adolescence. Amongst those that do, episodic memory is broadly reduced in terms of its specificity (Bruck et al., 2007; Goddard et al., 2014) but not necessarily in terms of its accuracy (e.g., Almeida et al., 2019; McCrory et al., 2007). Studies assessing specific memory details in autism often find that autistic children use less internal state language (Brown et al., 2012) and fewer links with the subjective experience to the self (Fivush, 2009). Together, these studies emphasise a tendency for autistic individuals to be more general when recalling past events manifesting difficulties retrieving specific episodic memories (e.g., Almeida et al., 2019; Henry et al., 2017; McCrory, Henry, & Happe, 2007; Millward et al., 2000). However, autistic individuals' memory difficulties can be attenuated depending on task demands, for instance, whether they recall (i) a recently self-experienced event over observed events (McCrory, Henry, & Happé, 2007; Millward et al., 2000), (ii) how much support is provided at test (e.g., Bowler et al., 1997) or (iii) depending on the type of questions posed (Bruck et al., 2002). Research on autistic adults demonstrates that difficulties in recall are diminished when support is provided at test (e.g., cued recall of an event) (Bowler et al., 2004). Likewise, Millward et al. (2000) found that autistic children performed equally well with verbal, mental age-matched non-autistics on a free recall task when recalling observed events compared to self-performed events. In this study, children went on two 25-minute walks. As they walked, children passed five distinct locations (e.g., a park, church, shopping centre, horse sanctuary and street). In each of these locations, the child experienced one event where the experimenter either used a verbal technique by commenting (e.g., "Do you want to go on the slide?") or using a nonverbal method (e.g., pointing to the horses). These events could be performed by the individual or events that the child observes another child experience. After the walk, children were asked to recall what happened using free-recall (e.g., "Tell me what happened") or cued recall (e.g., Can you tell me what you did in the park?). Whilst autistic children recalled fewer events performed by themselves than the observed events performed by a peer, there was no difference between the autism group and the neurotypical group matched for verbal ability for events experienced by a peer. The authors put forth the notion that there is a specific deficit in *personal* episodic memory in autism and not an underlying *general* episodic memory problem per se, given that there were no group differences in the recall of events experienced by an accompanied peer.

These findings suggest that the task's demands can differentially affect the outcome. For example, more substantial impairments were seen in autistic individuals relative to non-autistics for tasks that involve the free recall (i.e., remembering in the absence of any retrieval support) of complex stories, social stimuli or staged events compared to single-item word lists (for meta-analysis, see Griffin, Bauer, & Scherf, 2021).

Given episodic memory's importance for many social functions, including communicative interactions, because it allows us to retain and recall past episodes that can influence our social decision-making (Klein et al., 2009), it can be expected to play a role in autism, a condition, characterised in part by difficulties in interactions with others (American Psychiatric Association, 2013). Free-recall tasks are used to assess episodic memory in neurotypical and autistic groups. In this design, success requires the individual to encode the information successfully, recall previous events in memory (without cues/aids) and relay this information verbally. Therefore, failure on free-recall episodic tasks may not solely arise because the information was not recalled; but in relaying this information. Therefore, autistic children may be inherently disadvantaged because of the broader social communication impairments that accompany the condition. As detailed in Chapter 1, Autism Spectrum Conditions (ASC) are partly defined by social communication and interaction difficulties not accounted for by the overall developmental level. These difficulties in social communication and social interaction, including initiating and sustaining back-and-forth conversation and language skills, have been related to recall ability in autism (McCrory, Henry, & Happé, 2007). In addition, language and communication difficulties can constitute significant challenges in providing integrated narratives about past events (Boucher, 2012; Boucher et al., 2012; Dritschel et al., 2010). Research in other domains of cognitive functioning in autism has demonstrated that tasks relying on verbal instructions and answers can underestimate the autistic person's ability level (Dawson et al., 2007). In combination, therefore, autistic children may be disadvantaged by episodic memory tests requiring spoken communication.

Furthermore, tasks that rely on spoken communication may preclude the much-neglected assessment of episodic memory in non-speaking autistic children or those cognitively impacted (Tager-Flusberg & Kasari, 2013). To achieve this in the longer term, it is vital that we ensure tasks can be applied to the full spectrum and not only those without intellectual disability as well as their autism. We seek to contribute to the current literature by investigating whether autistic children exhibit differences in episodic memory when language-based demands associated with free-recall tasks are removed. The present study assessed episodic memory using the what-where-which EM task (EM test) described in detail in Chapters 2 and 3 of this thesis. The EM Test is a simple nonverbal EM task grounded in the behavioural components of episodic memory – e.g., the what-where-when or what-where-which aspects of a past event. These three disparate elements specific to that experience bind together in any combination to form a single episodic representation that can be recalled in a flexible way using a strategy of recollection (i.e., remembering, which involves reliving the associated details) (Holland & Smulders, 2011; Easton et al., 2012). In other words, one aspect of memory for an event (e.g., what) can enable us to recall the additional features and allow the subjective experience to be remembered as a whole.

The present experiment uses a real-world task involving hiding physical objects in locations within an actual physical space and context. Real-life episodic memories involve the spatial and contextual information helpful in discriminating between episodes (Eacott & Easton, 2010). However, to our knowledge, no studies have examined the memory performance of autistic children using a what-where-which occasion (henceforth, WWWhich) content-based episodic memory paradigm. In doing so, the present study allows us to address two overarching questions. First, can this particular task be used in this population group to assess episodic abilities, and if so, will episodic abilities mirror those found in the previous literature and show a difference compared to neurotypical participants? Secondly, how does other cognitive differences in autism, for example, in visuospatial working memory (i.e., lower forward digit span), short-term memory, and autistic traits (more significant social communication difficulties), influence performance?

To this end, we adopted a matched-group design to compare performance between groups of autistic and non-autistic children on episodic memory (using the what-where-which-task) and a series of tasks that measure other cognitive skills such as visual short-term memory (using the size JND task) and nonverbal visuospatial working memory (using the

Corsi-block Forward Span task). Here, we matched our groups based on mental age for theoretical reasons to allow for consideration of mental age, given that in autism, there can be a difference between chronological and mental age.

First, we investigated autistic and non-autistic children's recall of what, where and which elements of the hiding event (WWWhich). In this event, the child hides six different coloured pens in six separate predetermined locations within a toy kitchen, three in context one, then three different coloured pens in context two. After a brief retention interval, children's memory was tested by requesting children to find the coloured pens to complete a colouring task. In the recall test, children behaviourally located what item was hiding where (what-where test event), what item was hiding in which context (what-which event) and EM in its entirety (what item was hiding where in which context one/two [what-where-which EM test]). The EM Test required the binding of information for item identity ('what'), spatial location ('where'), and the physical context ('which occasion') into one representation. By separately analysing bound components within the EM Test, it was also possible to investigate further the memory-binding processes for item-location and item-context on EM representation within a single paradigm. For instance, chapter 3 showed that in neurotypical development that, EM follows a protracted developmental course improving until adolescence (Newcombe et al., 2007). The different components within an EM also develop at different rates (Picard et al., 2012). For example, recent research examining what-where-when memory using a nonverbal object placement task in 2-8-year-old non-autistic children found that successfully binding memory for the place (where) and temporal order (when) predicted success on the EM test (Mastrogiuseppe et al., 2019).

We predicted that if the task demands essentially eliminate difficulties in episodic memory for autistic children, then autistic children's memory performance may be maximised on the episodic WWWhich task by being able to demonstrate their memory of events without having to verbalise this to an experimenter. In addition, retrieval support will be for recalling events in the encoding environment. By contrast, consistent with the position that recalling relational information has repercussions for episodic memory in autism (discussed in detail in chapter 1; Gaigg et al., 2008; Gaigg & Bowler, 2013) because associative processes underpin the successful and spontaneous retrieval because associative processes underpin the successful and spontaneous retrieval of past memories, then performance in our autistic children should be reduced compared to non-autistic children on all three memory measures (WWWhich and its binding components; what-where, what-which). This is because the what-where-which occasion task requires disambiguating between two highly similar memories (where the incidental features of context, such as the background of the hiding apparatus in the current study, need to be bound to a memory of what location contains a specific object).

Second, given that episodic memory is relevant for social functioning (Campbell et al., 2015; Klein et al., 2009), and both EM and social functioning are in and of themselves associated with differences in autism, there should be a relationship between social functioning measured using the SRS-2 (Constantino, 2012) and EM performance (only used in those with an a priori diagnosis of autism [Kaat & Farmer, 2017]). Lastly, based on the cognitive profile of autism (discussed in Chapter 1) and the role of executive functions for EM in autism (Maister et al., 2013; McCrory, Henry, & Happé, 2007), we expected that visuospatial working memory and visual short-term memory should support episodic abilities. Based on the assumption that due to the visual nature of the task and the fact that all three memory measures rely on binding (what-where-which in its entirety, as well as its subcomponents [what to where, and what-which]), performance on all three tasks should require visuospatial working memory and visual short-term memory resources.

Therefore with this design, we can explore (i) whether a minimally verbal what-where-which occasion task can be used to assess episodic memory in autistic children and would the findings lead to a revaluation of their capabilities when language confounds associated with free-recall tasks are reduced (ii) whether the bound components (what-where, what-which) predict success on the WWWhich task, and, if so, are they underpinned by age-related improvements in binding item to occasion/location (iii) whether the ability to recall episodically is related to core autism symptoms (as measured by the SRS-2), and finally, (iv) whether episodic memory ability in the current task is supported by developments in other domains of cognitive functioning such as developments in visuospatial working memory and visual short-term memory. Together the findings would further our understanding of the episodic memory profile in autism and the underlying capacities facilitating episodic recall.

Therefore, the present study's objective was to explore these hypotheses using a minimally verbal paradigm in a more ecologically valid and developmentally appropriate paradigm than traditional measures of episodic memory.

4.3 Methods and materials

The method followed was the same as that for Chapter 3, aside from using the Wechsler Abbreviated Scale of Intelligence, Second Edition (WASI-II: Wecshler, 2011) to measure cognitive ability in Autistic children and the Social Responsiveness Scale, Second Edition, School-Age Form (Ages 4 to 18 years) (SRS-2: Constantino & Gruber, 2012) to quantity social behaviour in autistic children.

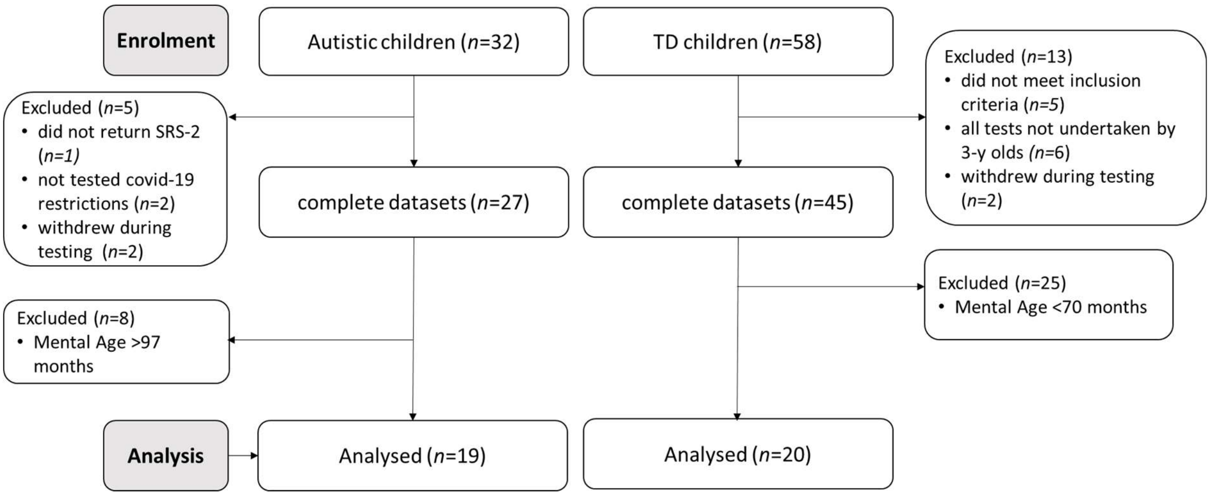
4.3.1 Participants

Thirty-two autistic children (4 female) were recruited for this study. For our neurotypical group, we used a subset of children from Chapter 3. Autistic participants were aged between 6 and 11 years (Autism: *M* = 8.61, *SD* = 1.47) with an estimated IQ ranging from 70 to 137 (*M* = 92.13, *SD* = 17.86). Participants were recruited through local mainstream schools, Durham University's families' database, and the developmental science research group's Facebook page. All participants in the autism group had previously received a formal diagnosis of autism and presented without intellectual disability. The Special Educational Needs and Disabilities (SEND) Coordinator at their school identified them for inclusion in the study. Alongside this clinical diagnosis, parents of the autism group further reported no additional diagnoses of a neurodevelopmental/neurological condition. It was impossible to obtain full datasets for all eligible autistic participants; reasons included voluntary withdrawal during testing and inability to complete all tests due to testing restrictions related to COVID-19 (see Figure 4.1 for the Flow of participants based on eligibility and exclusion criteria). To ensure that children in the groups were comparable, we created a subset of the data that included children with mental ages between 70 and 97 months. This range allows us to retain the highest number of children from each group while maintaining homogenous mental ages. The final sample of participants, therefore, consisted of 19 autistic children (3 female) aged between 70 and 97 months (Mdn=80) and 20 non-autistic children aged between 71 and 88 months (*Mdn* = 75). Participant characteristics are presented in Table 4.1.

A Mann-Whitney U test indicated that the groups did not differ significantly on mental age, $U = 234$, $p = .221$, Cohen's $d = .04$, $BF_{01} = 1.147$. Table 4.2 presents the results of the Mann-Whitney *U* test for the participant groups, and Figure 4.2 shows a violin plot for the distribution of mental age.

The Durham University, Psychological Research Ethics Committee, approved ethics for this research. Parents provided informed consent, and all children provided assent before taking part. The experimental sessions took place individually in a quiet room either at their school or within the laboratory at Durham University.

Figure 4.1 *Flow diagram of the progress for recruitment from enrolment to data analysis for the two participant groups.*



Note. The image shows the enrolment to data analysis for autistic and neurotypical children included in the study. The neurotypical children in the current study are a subset of children from Chapter 2 that were selected based on mental age (*n* = 20).

Table 4.1 *Participant characteristics (Autistic, Non-Autistic)*

Participant Characteristics	**Group**			
	Autistic		**Non-Autistic**	
	M	*SD*	*M*	*SD*
FSIQ-4	84.68	14.42	102.95	11.985
CA (years)	8.02	1.38	6.17	0.447
MA (months)	81.42	9.17	76.891	5.446
Verbal Comp (VCI; WASI-II)	80.05	21.81	-	-
Perceptual Reasoning (PRI) (WASI-II)	87.11	16.85	-	-
Verbal Comp (VCI; WPPSI-IV)	-	-	105.1	12.863
Visual-Spatial (VSI; WPPSI-IV)	-	-	100.95	15.391
SRS-2 T-score	82.68	6.00	-	-
SDQ	-	-	5.55	3.02

Note: MA = mental age (months), CA = chronological age (years), and FSIQ-4 = Full-scale Intelligence Quotient, measured using the WASI-II for the Autism group and the WPPSI-IV Non-autistic controls. MA = mental age equivalents were derived by using the age equivalents of the total raw scores on sixteen subsets on the Wechsler Preschool and Primary Scale of Intelligence –Fourth Edition for Non-autistic children (WPPSI-IV, Wechsler, 2012); and the four subsets on the Wechsler Abbreviated Scale of Intelligence – Second Edition

(WASI-II, Wechsler, 2011) for Autistic children. SRS-2 T = SRS-2 Total score is derived using the SRS-2 questionnaire.

Table 4.2 *Results from the Mann-Whitney U test examining FSIQ, CA, and MA between Autistic and Non-Autistic children*

Independent T-Test

	Test	**Statistic**	**df**	***p***	**Effect Size**
FSIQ-4	Mann-Whitney	58.500		< .001	-0.692
*CA (years)	Welch	5.572	21.556	< .001	1.803
*MA (months)	Welch	1.812	29.470	.08	.584

Note. The table shows the results of the Mann-Whitney U test examining the differences between Autistic and Non-Autistic children on FSIQ-4, CA, and MA.

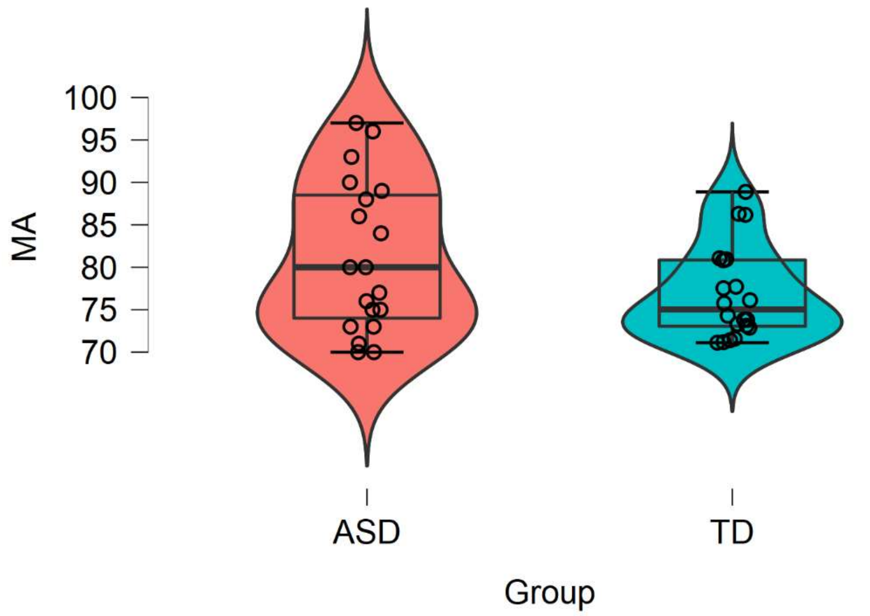
MA = mental age, CA = chronological age, and FSIQ-4 = Full-scale Intelligence Quotient, measured using the WASI-II for the Autism group and the WPPSI-IV Non-autistic controls.

MA = mental age equivalents were derived by using the age equivalents of the total raw scores on sixteen subsets on the Wechsler Preschool and Primary Scale of Intelligence – Fourth Edition for Non-autistic children (WPPSI-IV, Wechsler, 2012); and the four subsets on the Wechsler Abbreviated Scale of Intelligence – Second Edition (WASI-II, Wechsler, 2011) for Autistic children. For the Welch t-test, the effect size is given by Cohen's d. For the Mann-Whitney test, the effect size is provided by the rank biserial correlation.

*CA = An adjusted t-statistic based on the welch method was used to correct for unequal variances (*F* = 11.564, 37, p = .002).

*MA = An adjusted t-statistic based on the welch method was used to correct for unequal variances (*F* = 8.179, 37, p = .007).

Figure 4.2 *Violin Plot depicting the distribution of mental age between Autism and TD groups*



Note: violin plot illustrating the distribution of mental age (MA) in the two groups and its density. The length of each kernel represents density across the full range showing the distribution shape of the data. The wider portion of the violin indicates a higher density, and the narrow region represents a relatively lower density. The grey box with the whiskers in the violin is the boxplot. The box in the centre of each violin denotes the first and the third quartiles, 25th (Q1) and 75th (Q3) percentiles. No significant differences between the groups on mental age were noted $U = 234$, $p = .221$, Cohen's $d = .04$, $BF_{10} = 1.147$.

4.3.1 Cognitive Assessment

For autistic children, the Wechsler Abbreviated Scale of Intelligence, Second Edition (WASI-II) was used to assess cognitive ability. This cognitive assessment is suitable for individuals aged 6 to 90 years and has been used extensively with autistic children (e.g., Kim et al., 2018; Mayes & Calhoun, 2007; McIntyre et al., 2017; Troyb et al., 2014). The instrument consists of four subtests (block design, vocabulary, matrix reasoning, similarities) that yield a measure of FSIQ-4, verbal comprehension, and perceptual reasoning.

4.3.2 Social Responsiveness

Parents of autistic children completed the Social Responsiveness Scale, Second Edition, School-Age Form (Ages 4 to 18 years) (SRS-2; Constantino & Gruber, 2012). The SRS-2 is a 65-item standardised scale that quantifies social responsiveness related to autism as reported by parents, as outlined in the DSM-IV diagnostic criteria for Autism Spectrum Disorders (APA, 2000). Scoring of each item used a 4-point Likert scale from 1 ("not true") to 4 ("almost always true") to answer questions such as "Is aware of what others are thinking and feeling" based on the frequency of behaviour over the past six months. A total score for all 65 responses serves as an index of the severity of social skills. A T-score of 60 or above indicates clinically significant difficulties in reciprocal social behaviour (Constantino and Gruber, 2012). The SRS-2 has high sensitivity (93%) and specificity (91%) (Constantino and Gruber, 2012). It takes approximately 15 min to complete.

4.3.3 Analysis

Assumptions of normality; the dependent variable for the main episodic task has a binary outcome that is not normally distributed. As a result, nonparametric tests were used to analyse the data. All statistical comparisons were two-tailed, using $p < .05$ as the significance level. Analyses were undertaken through SPSS and the JASP 0.13.1 (2020).

Generalised Estimating Equations (GEE) were used to analyse memory performance as it allows for the analysis of repeated binary measurements of accuracy status. We selected an exchangeable working correlation matrix (this matrix structure is used for measurements from the same individual with no time dependence), specifying a binomial distribution with a logistic link.

We reported Bayes factors expressing the probability of the data given H1 relative to H0 (i.e., values larger than one favour H1. Kendall’s tau-b analysis was computed using default priors using the beta prior width of 1. Nonparametric equivalents of t-tests used a Cauchy prior of 0.707.

Bayes Factors for the outcomes of the main episodic and what-where/which bindings task, which consists of binary data (correct or not), were calculated using an online calculator designed specifically for binary data (see Appendix K) and described in Mazurek et al. (2015). The Matlab code and an executable of the calculator itself can be downloaded from http://www.jennyreadresearch.com/research/matlab-code/bayes-factors-for-binomial-data/.

To differentiate above-chance performance, we calculated the hypothesised probabilities for each test type (i.e., EM test, What-Where test, What-Which test) based on the three possible outcomes (0, 1, 2 correct) and the available hiding places (six locations) or context (one vs two) depending on the test. Due to violations of assumptions for the chi-square test for goodness of fit (1. that 80% of the cells have an expected frequency of greater than five; and 2. that no cell has an observed frequency of 0), it was necessary to recombine the three outcomes into two (i.e., no trials correct, and 1/more trials correct). Therefore, the probability of locating an item in the EM test and What-Where Test was specified as *Pr* = .66 (no trials correct) and *Pr* = .33 (one or more trials correct), respectively. The hypothesised probability for getting one or more trials correct on the what-which test was specified as *Pr* = .75.

As some participants attempted more than one retrieval (i.e., they opened a second box as the first attempt was incorrect), only the first response of each trial type (EM, what-where, what-which) was analysed.

Errors were identified as object errors and spatial errors. An object error would be incorrectly choosing a location where an item was present, but it was not the correct item. A spatial error would be incorrectly selecting a location where there never was a pen (i.e., an empty box). We also noted whether participants made revisit errors (visiting the exact location twice).

4.4 Results

All 39 children (Autistic *N*=19, Non-autistic *N*=20) matched on mental age correctly identified the colour swatches in the colouring task and completed the familiarisation task without repetition. In addition, all children revealed interest in the task at hand. Table 4.3 shows the mean performance on the Experimental tasks as a Function of Group

Table 4.3 *Mean Performance on the EM task and Visuospatial WM and Visual STM as a Function of Group*

Variable	**Group**			
	Autistic (*N*=19)		**Non-Autistic (*N*=20)**	
	M	*SD*	*M*	*SD*
What-Where-Which Task				
What-where-which	.79	.79	1.05	.61
What-where	1.11	.88	1.25	.72
What-which	1.37	.68	1.75	.44
Ancillary tasks				
VS Working Memory[a]	1.51	1.17	1.90	1.19
Visual STM[b]	19.16	5.86	20.15	2.06

Note. The table illustrates the mean accuracy across the two trials (getting none, one or two trials correct) for the WWWhich [full EM] test and its binding components as a function of group (Autistic, Non-Autistic) and the ancillary measures:

[a]Visuospatial Working Memory measured using the Corsi-Block Forward Span.

^{b}Visual STM measured using the size Just-noticeable difference task.

See Appendix O for raw data table for performance on the WWWhich task and ancillary tasks for Autistic (*N* = 19) and mental-age matched Non-Autistic Children (*N* = 20).

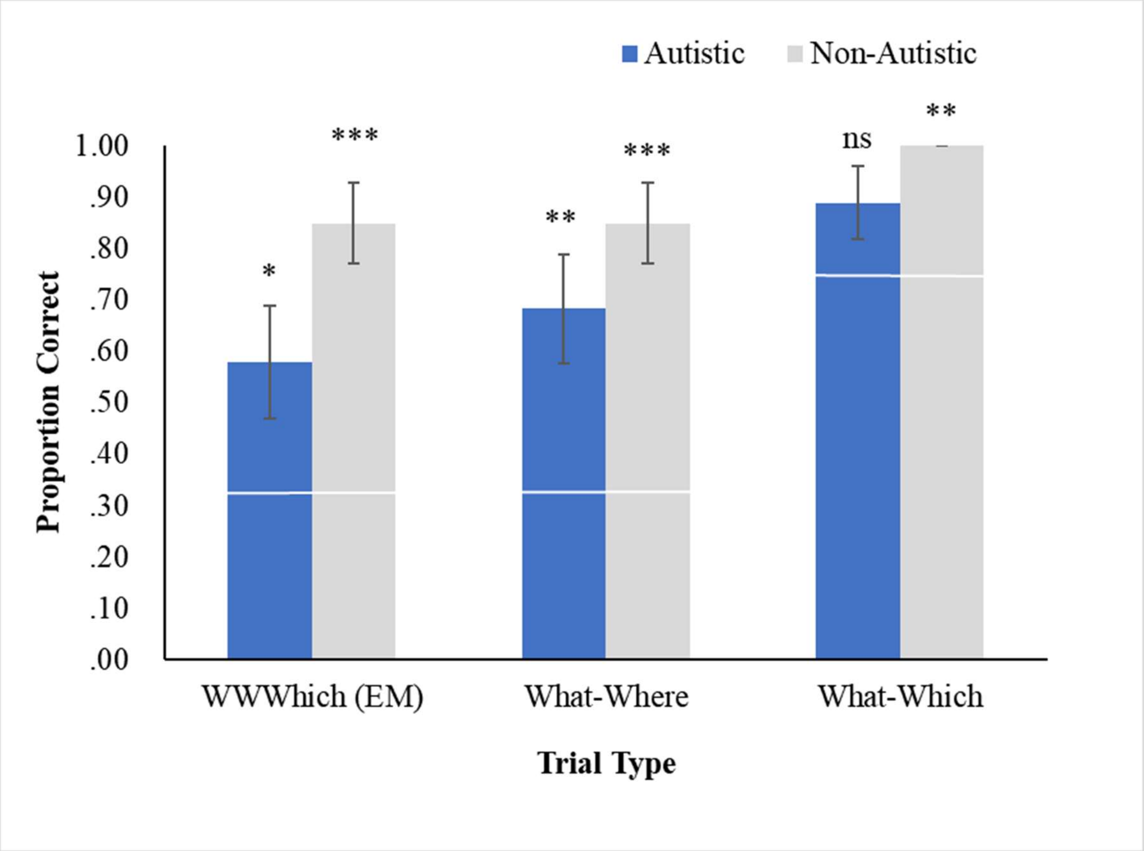
4.4.1 Temporal order

We began by testing for temporal order differences to eliminate the possibility that accurately locating items on the three memory measures (WWW, What-Where, What-Which) depended upon how recently the information was encoded (i.e., Time 1 vs Time 2). Results of the exact McNemar Test determined no significant changes in accuracy between Time 1 and Time 2 in any memory measures in either of the groups tested (all ps > .05). Hence, the data collected from Time 1 and Time 2 are considered together.

4.4.2 Performance in relation to chance

The probability of getting one or more discrete trials correct on the EM and What-Where Test by chance is .33. By chance, the likelihood of getting one or more discrete trials correct on the What-Which Test is .75. Children's performance was analysed relative to chance levels using a two-tailed binomial test. Results showed that autistic and non-autistic children's memory performance was significantly above what one might expect by chance alone for what-where-which (Autistic: p = .02; Non-autistic p < .001) and what-where (Autistic: p =.002; non-autistic: p <.001) tests (see Figure 4.3). As shown in Figure 10, non-autistic children performed close to ceiling for what-which trials and exceeded chance levels (p = .003) whereas autistic children, despite recalling 89% correctly did not exceed chance (p = .111).

Figure 4.3 *Memory performance (across two trials) in relation to chance levels as a function of trial type and group*



Note. The figure shows the proportion of correct responses by autistic (N = 19) and mental-age-matched non-autistic (N = 20) children for each memory combination of the WWWhich task. White lines indicate chance as proportions, set at .33 for WWWhich and What-Where, and .75 for the What-Which binding component. Asterisks indicate significantly above chance level, with * representing $p \leq .05$, ** representing $p \leq .01$, and *** representing $p \leq .001$. Ns indicate results that are not significant. Binomial tests showed that both autistic and non-autistic children performed significantly above chance levels for the WWWhich task and the What-Where binding combinations, with only non-autistic children performing above chance levels for the What-Which binding component.

4.4.3 Group-related differences in Memory

GEE analysis: We performed a Generalised Estimating Equations (GEE) analysis using the $N = 39$ matched data to examine whether group membership (Autistic, Non-Autistic) and test type (EM, what-where and what-which bindings) affect memory response accuracy (where the binary response was correct/incorrect). Group (Autistic, Non-Autistic) and trial type (i.e., EM, What-Where and What-Which) were entered as predictors. In addition, mental age (MA), chronological age (CA) and FSIQ-4 were entered as covariates to account for potentially confounding participant characteristics. The model examined the main effect of group (autistic and non-autistic), test type (WWWhich, What-Where and What-Which bindings) and their interaction together. In addition, the main effects of MA, CA, and FSIQ-4 on memory accuracy. Table 4.4 shows the ANOVA summary, and Table 5 shows the parameter estimates from the GEE model. Figure 3.4 shows the plot of mean accuracy by the group for each test type.

As seen in Table 4.4, there was no effect of group membership (Autistic, non-autistic) on memory accuracy rates: (p = .939, Bayes Factor = 0.060 (*BF* <.33 indicates some evidence for the null hypothesis (e.g., see Rouder et al., 2012); for Bayes Factor calculation, see Mazurek et al., [2015]) illustrating that autistic and non-autistic children were equivalent in accuracy. In contrast, the type of test had a highly significant effect (GEE (p): Wald X^2 = 24.276, $N = 39$, p <.001) on memory accuracy. Post-hoc analysis of the parameter estimates (see Table 4.5) showed on average, children in both groups experienced a 2.171-point (p < .001) decline in their memory accuracy on the episodic WWWhich task and a 1.450-point decline in accuracy on what-where task compared to what-which.

There was no main effect of chronological age, FSIQ-4, nor a significant interaction between group (autistic, non-autistic) and test-type (EM, What-Where, What-Which) on memory accuracy (all p >.05).

Table 4.4 *ANOVA Summary for GEE Model (Autistic, Non-Autistic Children)*

Effect	df	ChiSq	*p*
Group	1	0.006	0.939
TrialType	2	24.276	**< .001**
Group * TrialType	2	1.935	0.380
Trial number	1	.023	.879
FSIQ	1	1.532	0.216
CA	1	0.042	0.838
MA	1	1.626	0.202

Note. Generalised estimating equation (GEE) with binomial family and logit link function. This table demonstrates the ANOVA summary from the GEE analysis examining the main effects (and interaction) of Trial Type (WWWhich, What-Where, What-Which) and Group (Autistic, non-autistic) on memory accuracy (correct/incorrect) with FSIQ mental age (MA),

Table 4.5 *Analysis of the GEE parameter estimates, with accuracy as the outcome variable, and trial type and group as predictors and FSIQ-4, CA, and MA as covariates*

Term	Estimate	*SE*	*Wald* X^2	*P*	*Exp(B)*
Group					
Autistic	-0.535	.646	0.684	.408	.586
Non-autistic	0[a]				
TrialType					
WWWhich	-2.171	.528	16.930	**< .001**	**0.114**
What-where	-1.450	.591	6.027	**0.014**	**.235**
What-which	0[a]				
Group * TrialType					
Autistic * WWWhich	0.834	.709	1.384	.239	2.301
Autistic * What-where	0.877	.726	1.384	.227	2.404
Autistic * What-which	0[a]				
Trial Number					
First	.041	.266	.023	.879	1.041
Second	0[a]				
FSIQ-4	.027	.022	1.532	0.216	1.027
CA	.052	.255	0.042	0.838	1.053
MA	-.054	.043	1.626	0.202	0.947

Note. The table shows the analysis of the GEE parameter estimates, with accuracy as the outcome variable, trial number as a within-subjects factor, and trial type and group, and the interaction between Trial Type, and Group as predictors and FSIQ, CA (chronological age in years) and MA (mental age in months) as covariates.

4.4.3.1 Full dataset (N=69)

The above GEE analysis was replicated, including all participants (*N* = 69; Autistic: *n* = 24; Non-Autistic: *n* = 45), rather than the smaller matched groups. To eliminate age-related memory improvements as a contributing factor in our results, again, FSIQ, CA and MA were added as covariates. After accounting for CA, FSIQ and MA variations, results again showed no main effect of group: (GEE (p): Wald X^2 = .523, *N* = 69, p = .470), but a significant effect of test-type: (GEE (p): Wald X^2 = 37.517, *N* = 69, p <.001), no effect of trial number (GEE (p): Wald X^2 = .302, *N* = 69, p =.583) and no Group by test-type interaction: (GEE (p): Wald X^2 = .1.557, *N* = 69, p = .459) with no main effects of CA (Wald X^2 = .456, p=.500), MA (Wald X^2 = .855, p=.355) or FSIQ (Wald X^2 = .326, p=.568) on accuracy. Critically, we reaffirmed the main result of this study with more power to discern any effects; namely, autistic children perform equivalently to non-autistic peers in episodic memory, what-where and what-which bindings.

4.4.4 Examination of Errors

Table 4.6 shows the number of errors made by autistic and non-autistic children on the first attempt and overall (first and second attempts) across the two discrete trials for What-where-which and what-where memory measures. To determine why errors were made, we examined whether incorrect choices of the boxes that (1) contained a pen (object error) exceeded choices of those that (2) never contained pens (spatial error).

Wilcoxon signed ranks test revealed that the type of errors driving inaccuracy on the WWWhich task was similar for both groups: Autistic children made equivalent object errors

(*Mdn* = 1) and spatial errors (Mdn = 1) for the WWWhich test, $W = 36.000$, $p = .837$, $BF_{10} = .337$), as did non-autistic children; number of object errors (*Mdn* = 1) and spatial errors (*Mdn* = 1), $W = 33.000$, $p = .212$, $BF_{10} = .491$).

This was not the case for the what-where test: while there was no difference in the types of errors made by autistic children, $W = 24.500$, $p = .380$, $\mathrm{BF}_{10} = .405$), non-autistic children made significantly more object incorrect choices (Mdn = 1) than spatial errors (*Mdn=0*), $W = 45.000$, p = .005).

Table 4.6 *Errors on the first attempt across both trials as a function of group and memory measure*

Memory	Error Type	Attempt		Group	
What-Where-Which				*Autistic*	*Non-autistic*
	Object	First		12	12
			Both	***16***	***17***
	Spatial	First		9	8
			Both	***17***	***12***
	Revisit	First		2	0
			Both	**4**	**0**
What-Where					
	Object	First		9	10
			Both	**13**	**14**
	Spatial	First		5	3
			Both	**10**	**4**
	Revisit	First		3	2
			Both	**3**	**2**

Note. The frequency of object, spatial and revisit errors made by autistic (N=19) and non-autistic (N=20) MA-matched children on the first attempt (first), and both attempts across the two discrete trials of What-Where-Which and What-Where bindings. The maximum number of retrieval errors a participant could make on the first attempt was two per memory measure (one for each trial).

Object Error = incorrectly choosing a location where an item was present, but it was not the correct item.

Spatial Error = incorrectly selecting a location where there never was a pen (i.e., empty box). Revisit Error = visiting exact location twice.

4.4.5 Autistic Traits and Memory Retrieval

Autistic children (*N* = 19) exhibited clinically significant levels of autistic traits; all participants completed the SRS-2 (See Table 1: (*M = 82.68, SD = 6*).

To examine whether accuracy on the three memory measures (WWW, What-Where, What-Which) was not driven by the level of autistic traits for Autistic children, we assessed correlations between SRS- T-Scores and accuracy on the three memory measures (EM, What-Where and What-Which). None of the correlations were significant (all τb < .201, all p > .301, BF_{10} between .368 and .577). Bayes factor calculations between .33 and 3 suggest anecdotal evidence that memory performance is unrelated to autism heterogeneity in social functioning. As such this must be interpreted cautiously.

4.4.6 Effects of What-Where and What-Which binding on EM

To test whether performance on the WWWhich task was influenced by memory performance on the what-where and what-which task across the two trials we performed a GZLM analysis on autistic children's (*N* = 19) performance on the WWWhich task (None, One, or Both Trials Correct) as the dependent variable (with a fixed value of two trials) and what-where, what-which, chronological age (CA), mental age (MA) and FSIQ-4 as covariates. Non-significant interactions between predictors were removed from the analysis in a stepwise manner, starting with the highest interactions, until none remained. Results showed that autistic children's performance on the WWWhich task was independent of accuracy on What-Where (Wald X^2 = .001, p = .973), what-which (Wald X^2 = .454, p = .500), FSIQ (Wald X^2 = .426, p = .514), CA (Wald X^2 = .323, p = .570) and MA (Wald X^2 = .409, p = .523).

We replicated the above analysis with the subset of neurotypical children included in this chapter (*n* = 20) from Chapter 3 to examine whether What-Where and What-Which influence memory outcome in the episodic task using a smaller sample than that in Chapter 3. Accounting for FSIQ, MA and CA, again, we found no significant effects of what-where or what-which on episodic memory (p-values > .05 for all covariates).

4.4.7 Effects of Short-Term Visual Memory and Nonverbal Spatial working memory on EM

Before examining the contribution of nonverbal spatial working memory (WM) and short-term visual memory (STM) to performance across all three types of memory bindings, we first explored whether performance differed between Autistic and Non-autistic children for WM and STM using the Mann-Whitney U test. Analysis of the results revealed no significant difference between WM capacity (average Corsi forward span score) for Autistic (*Mdn* = 1.4) and Non-autistic children (*Mdn* = 1.8) $U = 150.500$, p = .271, $BF_{10} = .492$) or STM capacity: Non-autistic (*Mdn = 19.5*) Autistic children (*Mdn = 21*), $U = 213.000$*,* p = 0.522, $BF_{10} = .381$). The absence of group effects indicates that WM and STM responses were similar for both groups.

Second, to examine whether visuospatial working memory and visual short-term memory predict memory success, we conducted a GZLM procedure for each trial type separately by group. We included five measures: Corsi-Block FS task, size JND scores, FSIQ-4, CA, and MA as covariates. For autistic children, results of the three GZLM procedures showed that while none of the five covariates were significant for What-Where and What-Which binding combinations (all p-values >.05), only visuospatial working memory (Corsi Block FS) significantly predicted memory success (Wald $X^2 = 6.149$, p = .013; $\alpha Bonf = 0.05/3 = .016$) for WWWhich. Analysis of parameter estimates showed that autistic children with higher Corsi scores were 3.534 times more likely to accurately recall WWWhich events.

For non-autistic children, none of the five covariates were significant on any of the three binding combinations (all p-values >.05).

4.5 Discussion

In the present experiment, we used a nonverbal hide-and-seek paradigm to investigate the what-, where- and which occasion characteristics of episodic memory functioning (specifically addressing its integration for what-where and what which binding components) in autistic and MA matched non-autistic children. This approach focuses on the memory's content (rather than the experience). Thus, there were no requirements to verbalise specific memories to an experimenter explicitly.

Each experimental session used a single paradigm consisting of three tests (WWWhich [EM], what-where, and what-which) to assess the episodic memory profile of autistic and mental-aged matched peers. Children had to recall what was hidden (pen colour), where (location) it was hidden and in which context (Moon vs Forest) in a contingent manner. Simultaneously, we related performance to cognitive measures such as nonverbal spatial working memory and visual short-term memory. To the extent of our knowledge, no other studies have used this paradigm to assess the episodic memory profile in autistic children; therefore, we report the first evidence.

The main findings from this study are that there are no significant group differences in episodic memory performance between the two groups when controlling for differences in age and intellectual functioning. These results contradict the majority of published research and suggest that autistic children may not experience the same degree of episodic memory difficulties, particularly when assessed using a nonverbal episodic memory paradigm. Additional support for this conclusion comes from the Bayes Factor analysis, which further strengthens the evidence for no significant group differences. Although the performance of autistic children was slightly lower than that of non-autistic children, both groups were highly accurate in their memory performance, performing above chance levels on EM and What-Where memory measures. A notable exception was the performance of autistic children on the What-Which task, who did not reach above chance levels despite recalling object-temporal context correctly on 89% of trials. Nor were episodic abilities a manifestation of social functioning abilities in autism consistent with other studies (e.g., Lind, Bowler, et al., 2014). It is important to note that the small sample size of this study warrants caution in interpreting these findings. Therefore, future research with larger samples is needed to confirm these results.

A further goal of the present study was to examine whether performance in EM (and its binding components) is related to executive functions that change during childhood (e.g., visual-spatial working memory, visual short-term memory). First, we examined whether there were group differences in visuospatial WM and visual STM. Results found no significant differences in these measures between the two groups matched on mental age. However, due to variations in IQ and age, it could be that we were unable to detect group differences given the influence age and IQ can exert on performance (Colom et al., 2003; Engle et al., 1999; but see Habib et al., 2019). Nevertheless, our finding is not unprecedented, and other studies have similarly found no group differences in working memory while matching on age and IQ (Faja et al., 2016; Griffith et al., 1999).

A surprising result was that only the episodic recall ability of autistic individuals was influenced by visuospatial WM (controlling for potential influences of chronological age, full-scale IQ and mental age). In contrast, one would have expected to see this influence within both groups and potentially for all three binding combinations. This suggests that autistic children may rely more on visuospatial working memory in recalling episodically. Although our sample size is limited, our findings align with previous studies, which found significant relationships between executive functioning and memory recall (eye-witness recall) only in autistic adolescents (Bennetto et al., 1996; McCrory, Henry, & Happé, 2007).

Moreover, recent studies show that executive abilities predict performance in autobiographical memory (Goddard et al., 2014) and that spatial working memory training improves episodic memory performance in autism (e.g., Rudebeck et al., 2012). McCrory et al. (2007) speculated that weak central coherence might increase reliance on executive functions during recall. These findings suggest that executive functions may be particularly relevant for EM in autism.

As alluded to above, one possible explanation for the involvement of executive functions within our autism group in the EM task could potentially relate to task demands. For example, the full WWWhich task requires the retrieval and integration of multiple components, including the object, its location, and the temporal context in which they were presented to distinguish between two highly similar events. As such, the memory needs to be reconstructed holistically using context (Eacott & Norman, 2004). This may require executive functions such as attention, inhibition, and working memory to keep track of and integrate the various pieces of information (Diamond, 2013). In contrast, What-Where and What-Which require the retrieval and integration of only two components, which may be less demanding on executive functions and more reliant on other processes, such as perceptual and motor processes (Engelkamp et al., 1994; Wolbers & Hegarty, 2010). In addition, executive abilities are associated with episodic and relational memory in autistic children (see Maister et al., 2013).

Furthermore, tasks that involve visual information retrieval may also require more executive functions (Busch et al., 2005; Desaunay et al., 2020) because Busch et al. (2005) propose it is more effortful to keep an ongoing active mental representation for visual information. Interestingly, our observation was that autistic children tended to use overt and relevant self-talk, reconstructing, and systematically organising the order within which they hid each coloured pen, in each location, within each hiding context. Both inner (Alderson-Day & Fernyhough, 2015) and overt speech (Winsler & Naglieri, 2003) support tasks that require considerable mental effort (Gaillard et al., 2012). Moreover, previous research has linked difficulties in executive function with overt speech in autistic children (Winsler et al., 2007). Further research is needed to understand the specific cognitive processes involved.

As mentioned above, the present study indicates that success on the EM task was not underpinned by memory outcomes on the What-Which and What-Where bindings (while controlling for CA and FSIQ, MA) for autistic and non-autistic children. This suggests neither group relied on the **object-place** or **object-temporal context information** for integrated object-place-context configurations. Furthermore, because both WWWhich and WW are comparable in how easily they are to perform above chance levels on, which both groups did effectively, it reduces the possibility that the finding might result from differential demands of the subcomponent configurations. These findings are intriguing, and raise the possibility that the memory processes underlying successful episodic recall may differ from those required for object-place and object-temporal context associations (at least when measured using a what-where-which occasion task), a conclusion strengthened by our within-subjects design (but see Mastrogiuseppe et al., 2019).

Mastrogiuseppe et al. (2019) investigated memory for combining what, where, and when using a nonverbal object placement task in 2-8-year-old non-autistic children. The study involved hiding three different objects in five boxes positioned around a room, which the children had to replicate in the encoding phase, followed by a further re-enactment of their placement in the retrieval phase. For the what-where assessment, children were given three identical objects rather than three different ones as in the episodic task. The study found that successful memory binding for the place (where) and temporal order (when) predicted success on the episodic memory test, suggesting that binding spatial and temporal information is critical to full episodic memory. The authors concluded that spatial and temporal binding provides a scaffold upon which episodic memory develops (Mastrogiuseppe et al., 2019).

One explanation for our divergent findings might result from methodological differences. The operationalisation of episodic memory in the study by Mastrogiuseppe et al. (2019) differs from ours in functionally relevant ways. Most prominently in the operationalisation of the three components that make up a unique episodic occasion (what-where-when). What-where-when tasks (as is the case in the study by Mastrogiuseppe et al., 2019) define a unique occasion by its temporal context (i.e., how recently it was experienced, first, second, and so forth) rather than being differentiated (as is the case in our study) by contextual identifiers (distal and local visual elements) that separate two similar events, occurring on different occasions (Eacott & Easton, 2010). While the distinctive contexts in our study have temporal qualities, it is the integration of object and spatial location with temporal context that is crucial to accurate performance. To illustrate, in episodic trials, children experienced two different contexts on two different occasions that shared the same objects, and number of boxes but differed in the object's location depending on context. Successful recall, therefore, requires high-level precision to individuate the two experiences.

The structure of the task by Mastrogiuseppe et al. (2019) predicates that successful recall relies less heavily (in principle) upon the structural integration of all three components when re-creating the sequence of actions. The specificity required to represent and differentiate between two highly similar experiences might intuitively suggest greater integration to facilitate retrieval of the full episode (what-where-which). This would align with the finding that what-where-which tasks (in contrast to what-where-when) can only be accurately performed using recollection (Easton et al., 2012).

Taken together, our explanation serves to justify why full EM representation (what-where-which) in our task is not co-dependent on the separate bindings of what-where, or what-which because we cannot determine the individual contributions of what-, where- or which- components separately to full EM representations. As a result, we cannot decidedly know if our findings are incompatible with Mastrogiuseppe et al. (2019). Together these findings have theoretical implications. Theoretically, our findings suggest that the two minimal characterisations of episodic memory (what-where-when vs what-where-which) may rely on different memory processes. Nonetheless, we cannot reconcile the divergent findings and invite follow-up research to evaluate this possibility to help shed light on the nature of the underlying episodic memory processes in neurotypical and neurodivergent groups.

Finally, to better understand the reasons for errors on the WWWhich task we examined the types of memory errors that autistic and non-autistic children made on both the full episodic memory (EM) and what-where trials. Our analysis revealed that both autistic and non-autistic children exhibited similar error patterns that led to inaccuracies on the WWWhich episodic memory (EM) test. In particular, both groups were equally likely to search an empty location where there had never been an object and to search a location where an object had been placed, although not the correct one. This suggests that both groups may rely less on event-specific memory details, which may contribute to the errors made on the WWWhich task.

In contrast, on the What-Where memory task, non-autistic children were more likely to make an object error than to search an empty location, which suggests some evidence of general-event memory (e.g., "there was a pen in this box here," as opposed to "it never contained one"), but lacking the precision and specificity required for successful recall. Although both groups achieved similar overall levels of accuracy on the what-where task, further examination of the error patterns suggests potential differences between the two groups. Taken together, the findings suggest that more detailed descriptions and different analysis measures are essential. This study provides fresh insights into methodological considerations' role as a critical factor in understanding episodic memory differences in autism.

There are several reasons to account for our conflicting results. The first is that autistic children benefit from not recalling a past event verbally, resulting in a similar performance to their mental-age matched peers (while controlling for CA and IQ). In the current task episodic skills are measured using overt content demonstrations based on incidentally encoded information from single episodes. Episodic memory tests on which autistic children show disproportionate difficulties largely consist of the effortful learning of semantic information (i.e., either single words), which is later freely recalled or more complex experiences are verbally recounted. Success is measured in terms of accuracy and how detailed the information is to infer episodic capacity. Both measures rely predominantly on spoken language ability. Despite good verbal comprehension, by definition, autistic individuals have marked difficulties in social communication (APA, 2013). Thus, it might be possible that even by choosing well-matched samples, thereby reducing bias due to the covariates, a strict reliance on verbal recall may still underestimate their episodic memory ability. In this regard, Hayne and Imuta (2011) investigated episodic memory skills in young non-autistic children using verbal recall measures and behavioural re-enactment within a what-where-when paradigm. They found age-related differences in children's recall of object-place information disappeared for behavioural enactment, resulting in 3- and 4y olds being more comparable in their recall abilities.

While this example is not directly relatable to autistic children, it illustrates the possibility that we could be underestimating autistic children’s abilities when relying solely on spoken communication. Given that our task avoids dependence on verbal skills, relying on overt content demonstrations may potentially reveal similar episodic abilities between our two groups. It is certainly true that EM performance in Autism varies depending on the task and stimuli used (for review, see Boucher et al., 2012).

However, we must consider that our task could also be susceptible to solution by non-episodic strategies, particularly cueing and context reinstatement. Studies assessing cued recall have demonstrated equivalent levels of accuracy provided by autistic and non-autistic controls (Bowler et al., 2008; Maras et al., 2013; Maras & Bowler, 2010, 2012; Millward et al., 2000). Furthermore, reinstatement of the context of a to-be-remembered event may have augmented autistic children's memory performance. By directing individuals to the spatial context (for episodic and what-where measures only) to search for the hidden items, it is possible that being taken back to the actual spatial environment where the information was encoded can explain autistic children's comparable performance because less relevant information can be essentially ignored (Siegel & Castel, 2018) and potentially processed more deeply (Craik, 2002). Several converging lines of evidence suggest that self-enactment (i.e., self-performed actions) and context reinstatement (i.e., physically returned to the encoding context) can aid memory for that event (Hare et al., 2007; Lind & Bowler, 2009a, 2009b; Maras et al., 2013; Maras & Bowler, 2012; Summers & Craik, 1994; Williams & Happé, 2009; but see Zalla et al., 2010). This would align with the task support hypothesis (Bowler et al., 1997); providing support (here, using visuospatial information at encoding and retrieval with nonverbal retrieval methods) produces similar performance between autistic and non-autistic children. Effective retrieval cues can mentally reinstate the same contextual state at encoding (Rugg & Vilberg, 2013). The encoding specificity principle suggests it is easier to recall information when the context experienced at encoding and retrieval match (Tulving & Thomson, 1973). Maras and Bowler (2012) suggest that Autistic individuals have problems mentally reinstating the context experienced at encoding. The authors found when context reinstatement was supported by the same physical environment at encoding (such as returning to the same room in which they had experienced an event), this facilitated comparable recall for autistic individuals in terms of the number of specific details recalled and accuracy (Maras & Bowler, 2012). Cooper and Simons (2019), reflecting on which facets of memory are most relevant to understanding the autistic memory profile, emphasise how highly-context dependent it is.

Therefore, compared to other studies denoting difficulties in episodic memory in autism, our task is not a pure 'free-recall task', requiring bringing to mind information from the encoded event not presented during the test phase. Free-recall tasks are performed using recollection, a process associated with a feeling of *remembering*, which is considered truly episodic rather than *knowing*, which involves familiarity-based processes (Yonelinas, 1997, 2001, 2002). The former is associated with a highly context-dependent process. While we cannot relate children's performance with the subjective experience accompanying successful recall, we found that a recollection-based strategy of *remembering* was overwhelmingly reported for our typically developing adult sample (see chapter 2). Hence, we may speculate an episodic strategy consistent with free-recall. Other studies have also demonstrated that What-Where-When (Holland & Smulders, 2011) and What-Where-Which tasks (Easton et al., 2012) are associated with a recollective strategy of *remembering*. Thus, while participants may have used some sense of familiarity based on cueing - because they previously encountered the locations and background contexts, it does not necessarily follow that it is amenable to being solved using familiarity-based processes. Quite the opposite has been demonstrated in typical adults using a *what-where-which* episodic-like task; it is less amenable to being solved by such non-episodic strategies in adults (Easton & Eacott, 2008; Eacott & Easton, 2010). Moreover, given that we observed significant differences in performance within autistic and non-autistic children between the different memory measures (EM, what-where and what-which bindings), memory may not be driven entirely by cueing due to variations in performance. It is more likely that the nonverbal nature of our task essentially standardised the EM tasks' level of difficulty, making it no more difficult for autistic than non-autistic children.

Although this study had considerable strengths; we used a novel technique to investigate EM in autistic children (a relatively under-studied group compared to adolescents and adults with autism) with a broad demographic emphasising the heterogeneity of cognition in autism, and the task was conducted in incidental encoding conditions that typically occur in the real world rather than under intentional encoding which would confer a memory benefit because participants can engage in elaborative encoding (Craig et al., 2016; Yonelinas, 2002), it was limited in several respects. First, we could not draw definitive conclusions from some comparisons because our matched sample was relatively small and consisted of autistic children who varied significantly in IQ and CA while matched on MA with their non-autistic counterparts. For example, our findings of no difference in STM and LTM contradict the literature, necessitating further investigations in this area given the effect IQ and age can exert on STM (see Desaunay, Briant, et al., 2020). Second, unlike content-based tasks that examine the combination of what-where-when aspects of an experience, our emphasis was on integration; it precluded an assessment of memory for the individual elements that make up an episode, making it impossible to understand their contribution to episodic memory across development. Third, the study did not include a language-based assessment of episodic memory or a qualitative assessment of children's verbal strategies. Therefore, its relation with conventional assessment methods is unclear and makes it difficult to go beyond speculation regarding autistic and non-autistic children's different approaches to accomplishing the episodic task.

As such, while there are many ways in which our assessment may be improved upon or extended, the results still provide the basis for the potential of using this paradigm with non-speaking autistic children or those cognitively impacted, a neglected subgroup within autism research (Tager-Flusberg & Kasari, 2013). These under-researched groups may produce widely different memory profiles.

In conclusion, our findings reveal—for the first time—that the WWWhich episodic task can be used with autistic children. In this sense, this research was a first step toward understanding the impact of using a nonverbal and behavioural content-based task to measure episodic memory in autism. It suggests a new way to investigate and understand memory in autism. The absence of group differences in EM found in this study may reflect the non-linguistic methods used. We should, however, be cautious in our interpretations of the findings as we do not know whether nonverbal content-based models provide a more accurate measure of episodic memory as we did not investigate explicit verbal responses based on free recall methods.

Nonetheless, these data illustrate that how autistic children are tested influences our estimates of episodic memory skills. As such, while there are several ways to define and measure the construct of episodic memory, there is no real agreement on which test gets closest to capturing its elusive ability. However, each contributes to understanding the mechanisms underlying episodic memory. In the current study, we have demonstrated that autistic children do not exhibit a disproportionate difficulty in episodic memory, contrary to expectations based on current theories, when assessed using a nonverbal What-Where-Which paradigm. Although the involvement of WM for autistic children in EM suggests that alternative strategies are also being deployed in performing this task. Further investigation is necessary to gain a deeper understanding of the mechanisms behind these results and their implications.

5 General Discussion

5.1 Overview:

Historically the unique phenomenology that accompanies episodic memory has been central to differentiating episodic memory from other forms of long-term memory. However, this aspect of episodic memory is challenging to assess in the absence of language. The present thesis adopts Tulving's definition of EM as a memory store that stores information about events and the spatial-temporal relationships between them (Tulving, 1972, 2002a). As such, it adopts a minimal characterisation of EM, purportedly distinguishing it from semantic memory by the fact that the contents of What-Where-Which elements are simultaneously integrated into a holistic representation. The work presented in this thesis comprised a series of experiments that proceeded in multiple steps to develop a behavioural and low language methodological approach to assessing episodic memory and its binding components, first in adults and then in children (non-autistic and autistic). This overarching aim underpinned developing a paradigm that would overcome the theoretical, developmental, and diagnostic implications of requiring conscious recollection of past experiences (Tulving, 1983), which pose a considerable barrier to assessing memory in younger neurotypical children and autistic children because of the broader social communication differences that define the condition. The clear theoretical and practical advantage of such a real-life-like EM task combines the richness of real-life memories in which individuals interact with their environment in specific contexts and physical spaces with an objective approach by developing a what-where-which occasion episodic-like memory task where memory is captured through overt behaviour. While the main aims of the thesis were achieved, these findings will be discussed in light of related literature. Together, these studies offer fresh insights into the capacity and limitations non-autistic, and autistic children have in episodic memory when not relying on language, demonstrating methodological considerations' role as a critical factor in understanding episodic memory in developmental groups. Therefore, this concluding chapter begins by collectively considering these studies' contributions to our understanding of episodic memory in neurotypical adults, children, and autistic children. Then, describes the limitations inherent in the research presented herein, describing additional factors that may influence memory performance that falls outside this behavioural paradigm's remit. Before finally outlining some future directions for episodic memory research that could improve the generalisability of the findings and better elucidate the mechanisms underpinning differences in performance in episodic memory assessments in autism and prove helpful for including under-researched groups in research.

5.2 Summary of findings

First, Chapter 1 gave a broad overview of episodic memory in typical development and argued that a framework that relies heavily on the phenomenological experience of EM, accessed through conventional EM methodologies, can hamper young children’s task performance because it relies on verbal reports. It then argued that when it comes to understanding the memory profile in autism, restricting testing to one test format only (verbal descriptions) without a broader consideration of the social communication difficulties that stratify autism might impact our understanding of memory capabilities and vulnerabilities within this group. Critically, it is argued that episodic-like memory tasks, specifically those focussing on what, where, and which occasion behavioural content because it is less amenable to solution by non-episodic strategies, are potential candidates for examining episodic memory in children. Episodic-like tasks propose a minimal characterisation of episodic memory by focusing on the behavioural content of an experience and not its phenomenological character (i.e., the subjective states that distinctively accompany episodic memory; autonoetic [subjective sense of self-knowing] and chronesthetic [sense of subjective time underlying mental time travel] consciousness).

Across two experiments, Chapter 2 designed and refined the novel low language methodological approach (with specific considerations to avoid prominent sensory experiences to make the task accessible for future use with autistic children) implemented throughout this thesis using adults because they have a mature episodic system. Accordingly, Experiment 1a showed that the level of difficulty (10-box condition) posed a cognitive constraint (requiring inhibitory control) on adults' performance. This, together with feedback from participants, suggested the task was cognitively determined, which presented a fundamental problem with the methodology for future use with children and a pivotal deciding factor given the executive functioning difficulties (including cognitive flexibility [Leung & Zakzanis, 2014]) and inhibitory control [Geurts et al., 2014], core domains of executive function [Diamond, 2013]) reported in autism.

A subsequent experiment (Experiment 1b) investigated making the task much simpler by reducing the array of potential hiding locations making it less cognitively demanding for adults. The finding that adults were both highly accurate emphasised the suitability of the six-box version of the task, with most participants reporting a mental time strategy (e.g., remember rather than know) even if using a mental time strategy did not consistently guarantee they would be more accurate. Notably, this is not a recognition task; therefore, dissociating between the recollective aspects (remembering vs familiarity) is not directly comparable. However, adult versions of the what-where-which task by Easton et al. (2012) have discriminated between the two processes and found it is associated with a strategy of remembering. The finding that memory vividness underpinned memory recall in the 6-box condition suggests that it was a better overall measure of episodic memory contributing to a richer evaluation of the experience which contributed to the precision of EM. Lastly, surprisingly, performance on the WWWhich task was not predicted by how many words participants could learn in one exposure to the word list (RAVLT A1) nor by how well they retained that information over a 30-min retention interval (RAVLT A6-A7). While somewhat initially surprising, these findings can be interpreted in two different ways. First, it could be that the WWWhich memory task fails to capture the key features of episodic memory, which integrate single-exposure learning with long-term retention of information (Pause et al., 2013). Alternatively, it has been suggested that verbal learning tests in which participants are instructed to learn word lists/pictures, as is the case for RAVLT, are more likely to activate semantic memory (Pause et al., 2013). Given that the WWWhich task is less susceptible to solution by non-episodic strategies (Easton et al., 2012), the lack of a prediction supports the latter conclusion.

The findings from the final version of the What-Where-Which suggest it is a novel measure of long-term and incidentally encoded episodic memory. It fulfils the content criterion (Clayton & Dickinson, 1998), here what, where, and which features of a unique single experience in a simultaneous and integrated structure (Griffiths et al., 1999) by combining what object needs to be searched for, which context is present, and where it is located. This instantiated the what-where-which task's utility for future use with children (autistic and non-autistic) to refine our knowledge of the development of episodic memory in these groups.

Chapter 3 aimed to explore if our low-level language task could be used in neurotypical children of various ages (3-6 years in our sample) and examine if the binding components (what-where and what-which) are related to episodic memory and executive functions illustrating the mechanisms underpinning how EM develops. This was achieved by repeating the same procedure as in Chapter 2 but with some additional accommodations to make the task developmentally accessible to children by shortening the delay between encoding sessions, omitting the requirement of a verbal articulatory suppression task, and reducing the number of items children needed to retrieve.

The findings in Chapter 3 demonstrated the suitability of the task for children of all age groups (3-4, 5-6 years), specifically younger children, evidenced by the high levels of accuracy for the full episodic aspect of our task, which was not driven by older children (5-6 years), nor underpinned by age-related improvements in visuospatial working memory or visual short-term memory (for children over 4-years). We also observed similar performance patterns in younger (3-4 years) and older children (5y, 6y) in the what-where component, with both groups exceeding chance levels. In contrast, only older children (5-6y) exceeded chance on the what-which component of the task.

Paradoxically, 3-4-year-olds and 5-year-olds were more accurate than 6-year-old children, making more correct choices on the full EM task, with EM reaching maturity by 5 years of age. The enhanced performance of 3-4-year-olds on the full EM task relative to 6-year-olds certainly indicates that young children recalled all three elements (what-where-which occasion) of an event. Yet, their lower performance on the what-which task suggests that they may still be less adept at recalling contextual information. However, a ceiling effect in older children (5-6y) within the what-which binding condition suggests the what-which measure is not equally sensitive to variation in ability by failing to capture younger children's actual competence in the what-which task. Finally, in instances where children (of all ages) made errors, these were not wholly incorrect choices, suggesting available memory for the episode was general and not sufficiently specific enough to support accurate recall.

Chapter 3 also illustrates that the ability to recall specific past events located in a particular context and place does not depend on the ability first to bind what-where or what-which information but was dependent on age. This finding has implications for our understanding of the development of episodic memory, including suggestions of protracted development of the ability to contextualise events in their spatial locations. Recent research found that the where and when elements of memory (i.e., the spatial and temporal information of an event) emerge earliest in development, around the age of 3 years and scaffold episodic memory performance (Mastrogiuseppe et al., 2019). We anticipated that children who made correct What-Where (object-spatial location) and What-Which (object-temporal context) choices might also recall correctly on the full EM. Contrary to this expectation, we found no interdependency between full EM and its binding components. One explanation for this is that we were limited in capturing an effect due to various factors. For instance, the ceiling effect observed in older children (5-6y) within the what-which binding condition may have prevented us from capturing any potential age-related changes in contextualising what-which events, thereby masking effects on full EM performance. However, analogous results from a smaller subgroup of the same neurotypical children in Chapter 4 (and in our sample of autistic children) and adult participants in Chapter 2, experiment 1b lend further support to the finding that episodic memory, as assessed in this thesis, found episodic memory was not dependent upon what-where or what-which binding combinations. Even so, it is still essential to consider the different methodological approaches to studying episodic memory in previous research. One such difference regards the criteria we employed; what-where-which occasion. This uses temporal context to identify a unique episode and relies upon the simultaneous integration of the elements involved in an event (i.e., What-Where-Which occasion, what-where, and what-which events). Consequently, it imposed constraints which made it impossible to look at the relationship between isolated features such as ‘where’ or ‘which occasion’ without being confounded by ‘what’. As a result, it is not clear to what extent this has affected our results. One possibility which would allow us to adjust for object choice would be to incorporate a recognition test of object identity.

Together, the findings suggest, in line with close scrutiny of previous research, that EM has a protracted development with periods of regression demonstrated by 6-year-olds finding it difficult to retrieve episodic information despite advanced developmental age. The episodic skills required in our low language What-Where-Which tasks may be independent of the ability to bind object with spatial or temporal context information. This conjecture indicates that EM (measured using a what-where-which occasion characterisation of EM) might be inherently different and thus warrants further investigation.

One of the underlying aims of Chapter 4 and one of the main arguments of the thesis was that episodic memory paradigms should explore non-verbal methodologies to assess EM in younger neurotypical children and particularly with autistic children because of broader social communication difficulties that encompass a diagnosis of autism. As a result, Chapter 4 repeated the same procedure as in Chapter 3 with autistic children (6-11 years in our sample). The general question was could we use the task with autistic children, and if so, would their EM performance differ when compared with MA-matched counterparts when language demands are removed? The presented data indicated that despite exhibiting no significant differences in episodic memory performance when compared to non-autistic children matched on mental age, autistic children’s performance on the full EM version of the task, while unrelated to their autism characteristics, was related to visuospatial working memory (controlling for chronological age, full scale IQ and mental age). This was despite no group differences in executive measures, suggesting that employment of executive functions in our autistic children (specifically on the What-Where-Which measure) was not an effect of general executive functioning difficulties in the autism group. Indeed, as revealed in Chapter 1, while most of the literature reports a disruption in working memory in autism, between-group differences disappear when assessing visuospatial working memory abilities through spatial span forward tasks (e.g., using the Corsi block test) (Macizo et al., 2016; Ozonoff & Strayer, 2001; Williams et al., 2006).

Chapter 4 suggests our novel episodic memory is suitable for assessing what-where-which memory (and its binding components) in neurodevelopmental conditions such as autism. This was the first and only task to date that used an episodic-like memory task to assess recall of what-where-which memory in autistic children. While these results might seem to support the central premise of the thesis, caution is needed. The implications of these findings will be further discussed in the contributions to the literature section below.

5.3 Contributions to the Literature

One key contribution of this thesis was developing and testing a low language demand test of episodic memory that can be used to track episodic memory across childhood and autistic children. At the beginning of this thesis, it was noted that autistic individuals experience significant difficulties when recalling specific episodic events. However, limited research had examined episodic abilities in children younger than age 11 years, and they predominantly assessed their capabilities using explicit verbal responses. Chapter 4 demonstrated that autistic children are as accurate as their non-autistic counterparts in recalling highly specific episodic events, though some differences in performance were identified. The fact that autistic children were highly accurate, but their performance was interdependent on visuospatial working memory suggests that they achieve similar performance through alternative means. This conclusion seems logical because we know that the subjective experience of recollection is reduced in autism (Cooper & Simons, 2019), specifically the ability to reconstruct and monitor a past experience consciously. Thus, working memory should play a central role because it allows information encountered in the past to be retrieved, maintained, and manipulated (e.g., relating items), which we speculate may aid recall when a recollective strategy may be compromised. Support for this suggestion comes from studies which have found that executive ability was significantly correlated with episodic memories in autistic but not neurotypical children (11-14 years) despite no group differences in the executive functioning task, suggesting the effect is not due to differences in executive functioning in the autism group (Maister et al., 2013).

In contrast, the executive abilities of autistic children in the current study were not related to what-where or what-which bindings suggesting the three different memory measures do not necessarily pose the same cognitive demands for autistic children. This conclusion, though encouraging, remains tentative. It is based on the findings from one study with a fairly modest and reduced sample size due to the impact COVID-19 had on the ability to conduct face-to-face research with autistic children in schools. This raises concerns over the possibility of Type 1 errors. This conclusion, however, also does not consider the supportive conditions inherent in the paradigm that might support retrieval in autism. Therefore, rather than achieving similar performance through the low language demands of the task coupled with its dynamic real-world nature, better performance may result from supported recall conditions consistent with the task support hypothesis (Bowler et al., 1997, 2004). As mentioned in the introductory chapter of this thesis, the studies noting particular difficulties in episodic memory in autism involve the use of free recall tasks. These tasks require individuals to recall previously learned information without the aid of cues or guidance and as such are relatively unsupported. In contrast, the task hypothesis theory suggests that Autistic individuals will recall as much and as accurately as typical individuals if support is provided (see Bowler & Gaigg, 2008 for a review). One finding which harbours considerable empirical support and is particularly pertinent to this thesis is difficulties in source monitoring and memory for context by autistic individuals. These difficulties arise not because the context has not been encoded in the first place. Instead, there is a failure to utilise contextual information to aid recall. Recollection (unlike familiarity judgements) requires that the details of an episode are bound together by their spatial and temporal context information. Where one aspect fails, this can result in being unable to identify a specific episode because the episode's features are not sufficiently bound (Schacter et al., 1998).

However, when aided physically by being able to return to the same environmental context in which encoding took place, as was the case in the current thesis, autistic recall is enhanced to that of their non-autistic counterparts. These findings have important implications for the conclusions because they suggest that autistic children's episodic memory may have been enhanced simply by providing more supportive conditions. But this suggestion does not fully reconcile with the specific and effortful recruitment of executive functions for what-where-which memory (and not its binding components) despite support at retrieval (e.g., context reinstatement). Nonetheless, the lack of a condition that involved verbal recall under the same supportive conditions means these findings are limited in allowing us to discern whether it is simply returning to the encoding context or whether this, in combination with low language demands (compared to traditional EM tasks) coupled with the dynamic real-world nature of our task that aids recall. Thereby achieving equivalent performance actualised through different means. Therefore, one of the first lines of enquiry for future work is to include a verbally mediated condition.

The lessons learned from this thesis in exploring the use of a low language and minimal characterisation of episodic memory task provides valuable methodological guidance for later investigations which will benefit from the lessons learned in this exploration of what-where-which episodic memory. One valuable tool that incorporates the advantage of being behavioural, non-verbal, and sensitive for measuring subtle cognitive processes (e.g., attention [Hoang Duc et al., 2008] and executive functions [Grady et al., 2001; Milea et al., 2005]), are eye movement investigations. Importantly, they have been used effectively in young children and those with neurodevelopmental conditions (Falck-Ytter et al., 2013). This could help overcome the issue of context reinstatement and the advantage support provides to autistic individuals. Future research should adopt eye-tracking techniques—previous investigations by Ring et al., (2015) demonstrated that the allocation of attention at encoding is important for retrieval success in neurotypical adults, but not autistic adults, highlighting that even successfully encoded object-location relations do not result in retrieval success.

In addition, another point to consider is that the current thesis focuses solely on recalling non-social aspects of an event. While episodic memory is a fundamentally private experience of remembering personal episodes, a somewhat diary of internal events (Tulving, 1972), it plays a critical role in building and maintaining social relationships (Mar & Spreng, 2018) reflective of everyday experiences. Therefore, future work should extend this work to see if these findings still stand when social elements of events, not just those relating to objects and surroundings, need to be recalled. Given there is reduced attention to socially relevant information in autistic children and adults (e.g., Chawarska et al., 2010, 2012; Jones et al., 2008; for review Klin et al., 2002), it would be interesting to examine whether autistic children's performance would still be similar to their mental aged matched neurotypical counterparts.

5.4 Future directions

Traditional EM assessments (e.g., word learning, interviews, etc.) are challenging for young children; therefore, adopting behavioural techniques in research to permit children to communicate without expressive verbal language is particularly relevant. Similarly, autistic individuals who speak few or no words and those with intellectual disabilities represent an under-researched group (ID; Russell et al., 2019). The importance of adapting our methodological strategies is therefore critical to allow the meaningful inclusion of autistic participants to represent the whole autism experience respectfully.

This thesis has proposed a new instrument to evaluate episodic abilities in adults and children of various ages and neurodevelopmental populations, here Autistic children. This novel paradigm is an alternative to traditional methods with clear advantages for measuring the incidental encoding of information from one-trial learning into long-term memories for what, where, and which information, including assessing the binding of spatial and temporal contextual information.

The present thesis refined our current understanding of the episodic memory profile across ages and neurodevelopmental populations by extending existing findings of episodic memory that shows episodic recall does not relate to executive aspects of functioning in neurotypical participants; it relates explicitly to visuospatial working memory for autistic children despite supportive retrieval conditions. Although we have made some progress toward the goal of designing a real-world episodic task that is non-verbal in its implementation, the current approach invites follow-up research to overcome the theoretical implications of context reinstatement and the non-social focus of the task for neurodevelopmental groups such as autism. One logical progression that would clarify whether the absence of group differences in episodic recall indicated supportive retrieval conditions or whether it was related to the lower verbal demands would be to incorporate a verbal retrieval condition that could examine EM using explicit verbal communication in the absence and presence of context reinstatement. A final area of follow-up research is the finding that full EM was unrelated to its binding components. There are a small number of episodic memory studies that have incorporated eye-tracking technology in memory-research which have highlighted differences in the encoding and retrieval of episodic information in autism. Such techniques could help discern whether spatial and temporal context might relate to full EM differently than behavioural methodologies which allow the disparate combinations of what, where, and when by examining the encoding and retrieval strategies involved and the ways in which they influence each other rather than considering retrieval in isolation of these processes. This would have the added benefit of furthering our understanding of the potential absence/causes of difficulties in episodic recall with memory-related cognitive processes, such as attention (social versus non-social events) and executive functions and their scaffolding of autistic (and non-autistic) children's performance. As mentioned in the introduction of this thesis, other behavioural paradigms adopting a minimal characterisation of EM (e.g., What-Where-When task) inspired the development of the paradigm used throughout the current thesis.

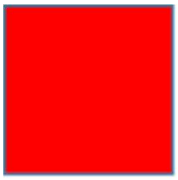
Here, we investigated three measures of memory (full EM, What-Where, and What-Which) within the same What-Where-Which occasion paradigm. Combining different methods and memory paradigms enables us to investigate the different components of memory without deciphering which test brings us closer to capturing episodic memory in the absence of its unique phenomenology.

5.5 Conclusions

The current thesis views episodic memory as past experiences anchored to a specific spatial and temporal context. In conclusion, we found that autistic children do not have disproportionate difficulties in episodic memory in so far as its contents. Crucially, by reducing language confounds, we offered insights into the mechanisms of EM and the nature of memory difficulty in autism, which would not be observable with standard approaches. Of course, this is only the first layer in understanding the episodic memory profile in autism. The content alone does not constitute the richness, complexity and quality of memories accessed using language. These episodic details are recalled in recollection judgements, which evidence suggests is reduced in autism. It thus seems unlikely that viewing EM from solely one perspective (content or its experience) will strike a balance between capturing its elusive ability, on the one hand, with the need to develop procedures relying less on the experiential qualities accompanying EM. However, such a balancing act is not always possible. In the case of very young children, non-speaking autistic children or those cognitively impacted, examining the fundamental associative elements of EM without language constraints will contribute to our understanding of EM across a wide range of ages and abilities and allow for their meaningful inclusion. The findings of this thesis will hopefully put us closer to a position to be able to do this.

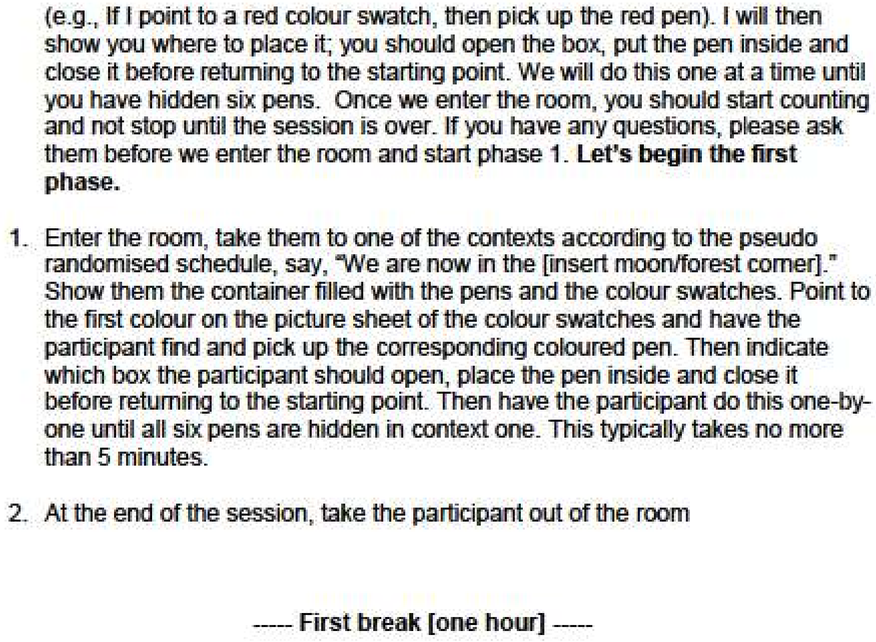
6 Appendices

Appendix A: **Chapter 2: Colour-naming task used in experiments 1a and 1b**



Appendix B: **Chapter 2: Examples of toys used in experiment 1b**

Appendix C: **Chapter 2: Protocol with standard instructions for Experiment 1a**



(e.g., If I point to a red colour swatch, then pick up the red pen). I will then show you where to place it; you should open the box, put the pen inside and close it before returning to the starting point. We will do this one at a time until you have hidden six pens. Once we enter the room, you should start counting and not stop until the session is over. If you have any questions, please ask them before we enter the room and start phase 1. **Let's begin the first phase.**

1. Enter the room, take them to one of the contexts according to the pseudo randomised schedule, say, "We are now in the [insert moon/forest corner]." Show them the container filled with the pens and the colour swatches. Point to the first colour on the picture sheet of the colour swatches and have the participant find and pick up the corresponding coloured pen. Then indicate which box the participant should open, place the pen inside and close it before returning to the starting point. Then have the participant do this one-by-one until all six pens are hidden in context one. This typically takes no more than 5 minutes.

2. At the end of the session, take the participant out of the room

----- First break [one hour] -----

Session 2: "multitasking" encoding 2

1. Before the participant arrives, put the different coloured pens in a container situated on a desk in front of the two contexts in a central location, with the picture sheet of the colour swatches next to it for session 2.

2. Remind the participant of the instructions given before session 1. Read these instructions to the participant: This time, we will see if performance has improved with practice (and we needed to leave it an hour to consolidate). So, just as we did in the first session in the [moon/forest corner] before lunch, we are going to hide another six coloured pens, but this time in the [moon/forest corner] while you count in ascending order (e.g. 123456). Once we enter the room, I would like to begin counting, so please ask them now before we enter the room if you have any questions.

3. Enter the room, but now take them into the other context, say, "We are now in the [insert moon/forest corner]", and repeat the task, but with different coloured pens and locations.

4. Take the participant back out of the room [if possible. If not, run the next phase in the same room].

---- **Second break one hour delay** -----

** run a battery of tests during this interval in the following order **

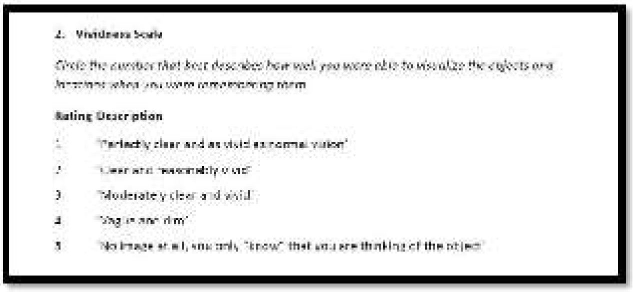
1. Stroop,
2. Trail making A & B Task,
3. Rey-Auditory Verbal Learning Test.

<u>Session 3</u>: Retrieval: Colouring task

1. Debrief participants about t tell them the real purpose of the task. Ask them if they suspected the task was a memory task, make a note of their response.

2. Tell participants that once inside the room you will show them two sets of pictures; one labelled the moon corner and the other marked the forest corner. On each picture sheet, there will be six images. I would like you to match each image by finding the corresponding coloured pen in the order stated on the sheet for the [insert moon/forest] corner first; then, we will do the same thing for the other corner. Tell participants, "You can only open one box at a time, so feel free to take your time, there is no time limit". Once you have chosen a box to open, I would like you to open it; if it is the correct pen, I would like you to pick up the pen, close the box and put the pen in this cup holder before moving on to find the next pen. If you cannot retrieve the target pen, please leave the pen in the box and close the lid we will move on to the next image. I will give you another chance to go back for a second time at the end of the retrieval session.

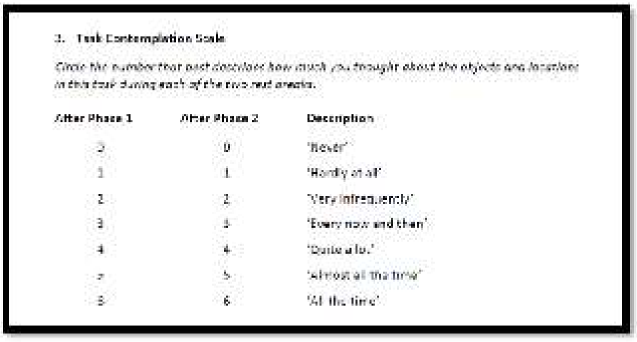
3. Ask them to complete the vividness scale and the task contemplation scale



2. **Vividness Scale**

Circle the number that best describes how well you were able to visualize the objects and locations when you were remembering them

Rating	**Description**
1	'Perfectly clear and as vivid as normal vision'
2	'Clear and reasonably vivid'
3	'Moderately clear and vivid'
4	'Vague and dim'
5	'No image at all, you only "know" that you are thinking of the object'



3. **Task Contemplation Scale**

Circle the number that best describes how much you thought about the objects and locations in this task during each of the two rest breaks.

After Phase 1	**After Phase 2**	**Description**
0	0	'Never'
1	1	'Hardly at all'
2	2	'Very infrequently'
3	3	'Every now and then'
4	4	'Quite a lot'
5	5	'Almost all the time'
6	6	'All the time'

4. Debrief participants again (verbally and in written format).

Protocol

(Standard Instructions for adult participants)

Greeting

Hello, my name is…..

Thank you for participating in this study

Session 1: "multitasking" encoding 1

For adults:

1. Before the participant arrives, put the different coloured pens in a container situated on a desk in front of the two contexts in a central position, with the picture sheet of the colour swatches next to it for session 1. The reason for having participants find the pens from a container using the picture sheets is to encourage them to pay attention to the colour of the pens

2. When the participant arrives, first give them an information leaflet explaining the study, talk them through the study, and have them read and sign the consent forms. Also, have them complete the colour-naming task (and give a reason why: part of the task requires that you have no known colour deficiency, so we would like you to name the colours on this sheet before we start).

3. Because the aim is to induce incidental memorisation, a cover story regarding the study's objective is used. Therefore, read the following instructions to the participant:

   Cover story: "We are conducting a multi-tasking study and want to investigate how well people perform a verbal task under distracting conditions. The task itself will take place in three parts. There will be two multitasking sessions (each separated by an hour) where you will perform the cognitive distraction task. Then in the final phase, we will ask you to complete two colouring activities and a short battery of cognitive assessments.

   In each multitasking session, you will begin counting aloud in ascending order, e.g. 123456) once in the room while I distract you with a motor task. I will audio record the sessions to measure your ability to perform the counting task while distracted. For the distraction task, I will take you to a specific location in the room and show you a piece of paper with colour swatches on it. I will point to a colour on the sheet, in the order indicated on the sheet, and I would like you to pick up the coloured pen that corresponds to that colour

Appendix D: **Chapter 2: Protocol with standard instructions for Experiment 1b**

Protocol

(Standard Instructions for adult participants)

Greeting
Hello, my name is…..

Thank you for participating in this study

Session 1: "multi-tasking" encoding 1

For adults:

1. Before the participant arrives, put the different objects in a container situated in the context that you will be hiding the objects, with the picture sheet of the objects next to it for session 1. The reason for having participants find the objects from a container using the picture sheet is to encourage them to pay attention to the identity of the objects.
2. When the participant arrives, first give them an information leaflet explaining the study, talk them through the study, and have them read and sign the consent forms. Also, have them complete the colour-naming task (and give a reason why: part of the task requires that you have no known colour deficiency, so we would like you to name the colours on this sheet before we start).
3. First, ask participants to count the number of trees/stars on the banners (this is to draw their attention to the different contexts). Then, for the locations, ask them to count the number of boxes that open towards them and how many boxes open the opposite way. Finally, participants stayed within the encoding context for the duration of the hiding session rather than walking back and forth from a central point to collect objects. Again, the reasoning was to minimise the fragmentation of the experience.
4. Because the aim is to induce incidental memorisation, a cover story regarding the study's objective is used. Therefore, read the following instructions to the participant:

   Cover story: "We are conducting a multi-tasking study and want to investigate how well people perform a verbal task under distracting conditions. The task itself will take place in three parts. First, there will be two multi-tasking sessions (each separated by an hour) where you will perform the

cognitive distraction task. Then in the final phase, we will ask you to complete two colouring activities and a short battery of cognitive assessments.
In each multi-tasking session, you will begin counting aloud in ascending order, e.g. 123456) while I distract you with a motor task. I will let you know when to start counting. I will audio record the sessions to measure your ability to perform the counting task while distracted. For the distraction task, I will take you to a specific location in the room and show you a piece of paper with pictures on it. I will point to an image on the sheet in the order indicated on the sheet, and I would like you to pick up the toy that corresponds to that image, and I will show you where to hide it. Before we do this task, I will ask you some questions about the items in the room.

1. Familiarisation with contexts and locations: Enter the room to draw attention to the contexts and hiding locations (which could be at the back of the hiding apparatus). First, ask participants to count the number of trees/stars on the banners. Then ask them to count the number of boxes that open towards them and how many boxes open the opposite way.

2. Ask the participant to start counting in ascending order, take them to one of the contexts according to the pseudo randomised schedule [and stay within this context for the duration of session 1], say, "We are now in the [insert moon/forest corner]". Show them the container filled with the objects and the picture sheet with images of the objects. Point to the first image on the picture sheet and have the participant find and pick up the corresponding toy. Then indicate which box the participant should open, place the object inside and close. Then have the participant do this one-by-one until all six objects are hidden in context one. This typically takes no more than 5 minutes.

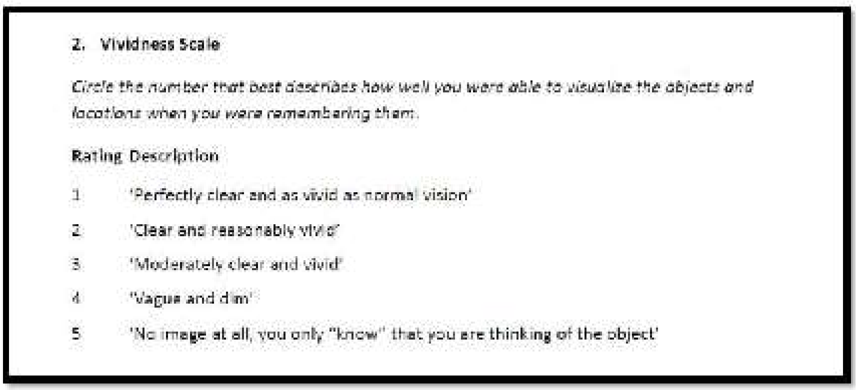
3. At the end of the session, take the participant out of the room

----- **First break [one hour]** -----

Session 2: "multi-tasking" encoding 2

1. Before the participant arrives, put the different objects in a container situated in the second context, with the picture sheet of the objects next to it for session 2.

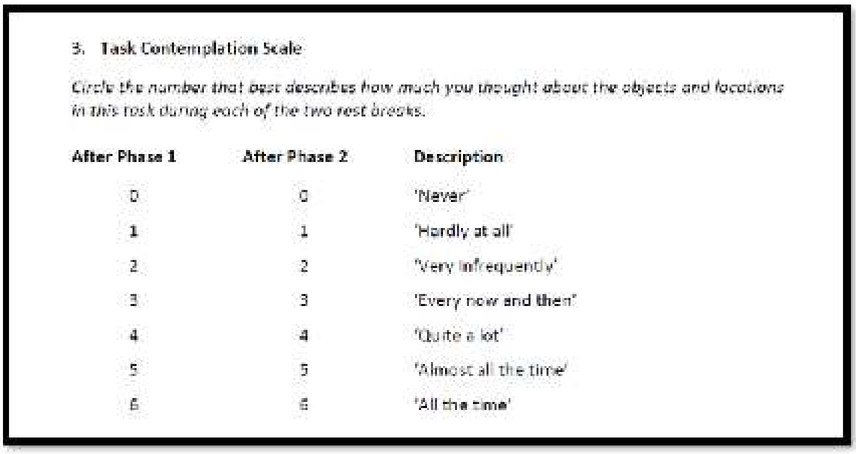
2. Remind the participant of the instructions given before session 1. Then, read these instructions to the participant: This time, we will see if performance has improved with practice (and we needed to leave it an hour to consolidate). So, just as we did in the first session in the [moon/forest corner] before lunch, we are going to hide another six objects, but this time in the [moon/forest corner] while you count in ascending order (e.g. 123456). Once we enter the room, I would like to begin counting, so please ask them now before we enter the room if you have any questions.



2. Vividness Scale

Circle the number that best describes how well you were able to visualize the objects and locations when you were remembering them.

Rating	Description
1	'Perfectly clear and as vivid as normal vision'
2	'Clear and reasonably vivid'
3	'Moderately clear and vivid'
4	'Vague and dim'
5	'No image at all, you only "know" that you are thinking of the object'



3. Task Contemplation Scale

Circle the number that best describes how much you thought about the objects and locations in this task during each of the two rest breaks.

After Phase 1	After Phase 2	Description
0	0	'Never'
1	1	'Hardly at all'
2	2	'Very infrequently'
3	3	'Every now and then'
4	4	'Quite a lot'
5	5	'Almost all the time'
6	6	'All the time'

4. Debrief participants again (verbally and in written format).

Appendix E: **Chapter 3: Familiarisation Task**

Appendix F: **Chapter 3: Photograph of the eight different colouring pens**

Appendix G: **Chapter 2: Example set of unique colour swatches used in each hiding session (6 per session)**

Hiding Session 1

🟥 **1**

🟫 **2**

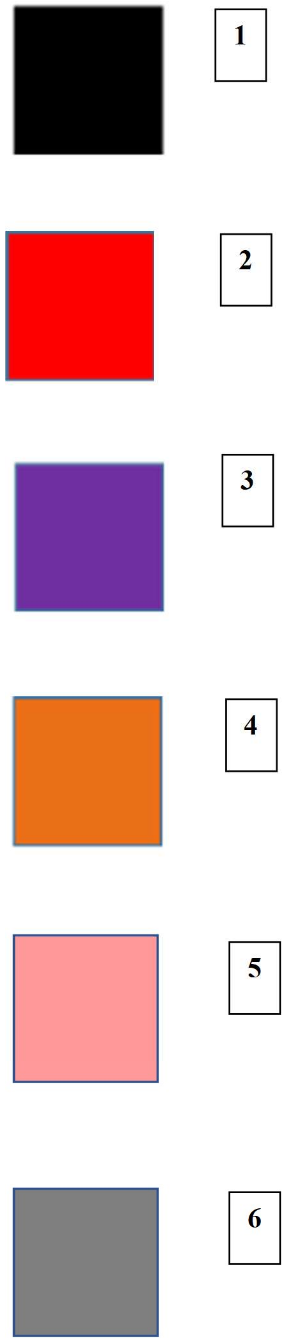
🟦 **3**

⬛ **4**

🟩 **5**

🟨 **6**

Hiding Session 2



Appendix H: **Chapter 2: Protocol for Error Identification**

Appendix H: Chapter 2: Administration protocol for errors

Protocol

The protocol outlined below outlines the procedures to be followed by both the participant and the experimenter in the event of an error during the testing phase of the What-Where-Which memory task and its binding combinations. This protocol applies to all three memory combinations: What-Where-Which (full EM), What-Where, and What-Which. The errors are classified into three categories: object errors, spatial errors, and revisit errors. An object error occurs when the participant selects an incorrect item in a location where an item was present. A spatial error occurs when the participant selects a location where no item was present. A revisit error occurs when the participant revisits a location that has already been opened.

Note: The What-Which memory combination is assessed by requiring the participant to select a context in which to search for an item. Although finding the item's exact location is not necessary for success in the trial, the participant is still required to search for it. In the event that the participant opens an incorrect box (either in the correct or incorrect context), the experimenter will record the context and location and follow the steps below.

Variants:

1. **The participant opens an empty box**:
    a. If the box has **not been opened previously**, the participant closes the box and moves on to the next item on the schedule. The experimenter records this as a **spatial error** and the participant is allowed a second attempt at retrieving the correct item following the completion of the trial.

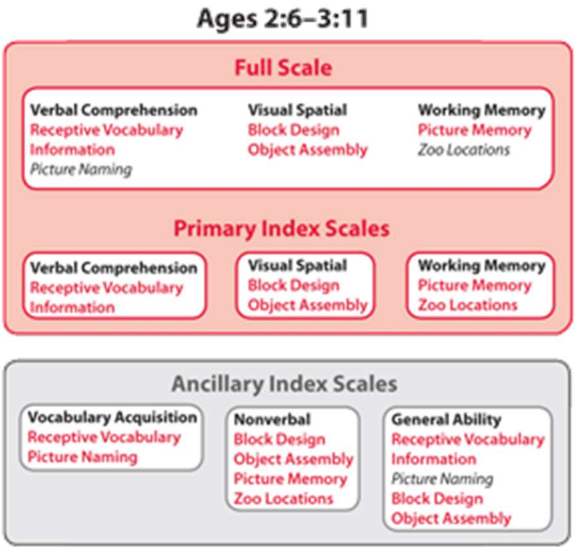
   b. If the box **has been opened previously**, the participant closes the box and moves on to the next item on the schedule. The experimenter records this as a **revisit error**, and the participant is allowed a second attempt at retrieving the correct item following the completion of the trial.

2. **The participant opens a box containing an incorrect item:**
   a. If the box has **not been opened previously**, the participant leaves the item inside the box, closes the lid, and moves on to the next item on the schedule. The experimenter records the error as an **object error**. If the item seen is one of the next items on the schedule, the participant is allowed to find the item. The experimenter then implements a manipulation to the schedule, requesting the participant to find an item that corresponds to the same memory combination (there are two of each memory combination in each context). The participant is allowed a second attempt at retrieving the correct item following the completion of the trial.

   b. If the box **has been opened previously**, the participant leaves the item inside the box, closes the lid, and moves on to the next item on the schedule. The experimenter records the error as a **revisit error**. At this step, the experimenter is not required to implement further manipulation to the schedule as this was done previously when the box was opened incorrectly during the first attempt. The participant is allowed a second attempt at retrieving the correct item following the completion of the trial.

Any items recalled correctly on the subsequent second attempt are recorded. However, only the results from the first attempts are included in the analyses

Appendix I: **Chapter 3: Core subsets of the WPPSI-IV**



Ages 2:6–3:11

Full Scale

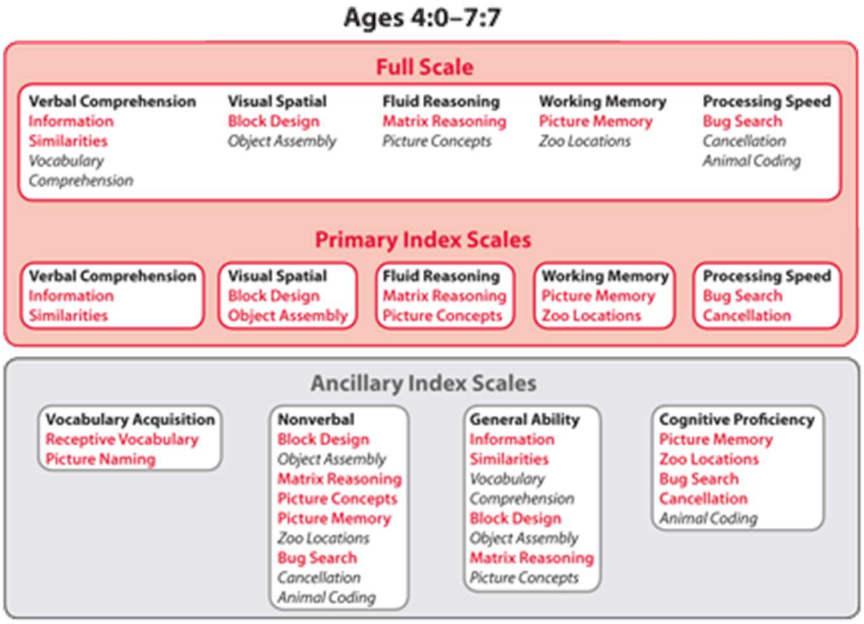
- **Verbal Comprehension**
  - Receptive Vocabulary
  - Information
  - *Picture Naming*
- **Visual Spatial**
  - Block Design
  - Object Assembly
- **Working Memory**
  - Picture Memory
  - *Zoo Locations*

Primary Index Scales

- **Verbal Comprehension**
  - Receptive Vocabulary
  - Information
- **Visual Spatial**
  - Block Design
  - Object Assembly
- **Working Memory**
  - Picture Memory
  - Zoo Locations

Ancillary Index Scales

- **Vocabulary Acquisition**
  - Receptive Vocabulary
  - Picture Naming
- **Nonverbal**
  - Block Design
  - Object Assembly
  - Picture Memory
  - Zoo Locations
- **General Ability**
  - Receptive Vocabulary
  - Information
  - *Picture Naming*
  - Block Design
  - Object Assembly



Ages 4:0–7:7

Full Scale

- **Verbal Comprehension**
  - Information
  - Similarities
  - *Vocabulary*
  - *Comprehension*
- **Visual Spatial**
  - Block Design
  - *Object Assembly*
- **Fluid Reasoning**
  - Matrix Reasoning
  - *Picture Concepts*
- **Working Memory**
  - Picture Memory
  - *Zoo Locations*
- **Processing Speed**
  - Bug Search
  - *Cancellation*
  - *Animal Coding*

Primary Index Scales

- **Verbal Comprehension**
  - Information
  - Similarities
- **Visual Spatial**
  - Block Design
  - Object Assembly
- **Fluid Reasoning**
  - Matrix Reasoning
  - Picture Concepts
- **Working Memory**
  - Picture Memory
  - Zoo Locations
- **Processing Speed**
  - Bug Search
  - Cancellation

Ancillary Index Scales

- **Vocabulary Acquisition**
  - Receptive Vocabulary
  - Picture Naming
- **Nonverbal**
  - Block Design
  - *Object Assembly*
  - Matrix Reasoning
  - Picture Concepts
  - Picture Memory
  - *Zoo Locations*
  - Bug Search
  - *Cancellation*
  - *Animal Coding*
- **General Ability**
  - Information
  - Similarities
  - *Vocabulary*
  - *Comprehension*
  - Block Design
  - *Object Assembly*
  - Matrix Reasoning
  - *Picture Concepts*
- **Cognitive Proficiency**
  - Picture Memory
  - Zoo Locations
  - Bug Search
  - Cancellation
  - *Animal Coding*

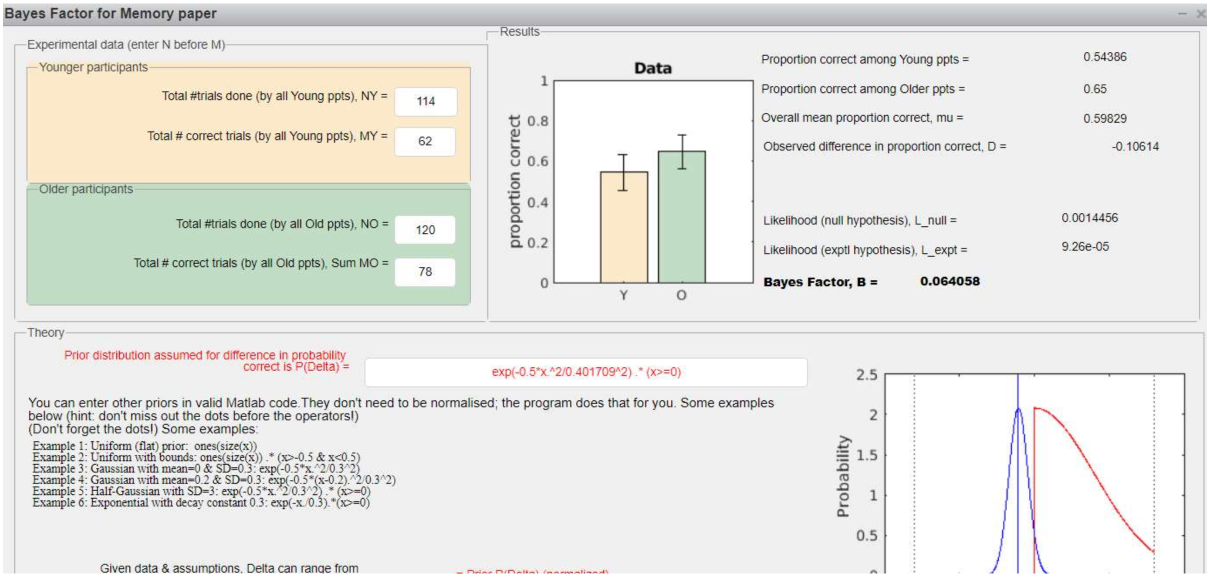
Appendix J: **Chapter 3: Corsi-Block (layout and Size)**

The computerized Corsi-Block procedure (Hamilton, 2017) was administered using the ASUS Notebook PC T100 series, specifications as follows:

- Display:
  - 10.1 inch 16:9 IPS High Density resolution of 1366 x768 pixels with Multi-Touch Screen
- Dimensions:
  - Tablet: 263 x 171 x 10.5 mm (WxDxH)

.

Appendix K: **Chapter 4: Online Bayes calculator for binary data**



Total #trials done (by all Young ppts), NY = 114

Total # correct trials (by all Young ppts), MY = 62

Total #trials done (by all Old ppts), NO = 120

Total # correct trials (by all Old ppts), Sum MO = 78

Proportion correct among Young ppts = 0.54386

Proportion correct among Older ppts = 0.65

Overall mean proportion correct, mu = 0.59829

Observed difference in proportion correct, D = -0.10614

Likelihood (null hypothesis), L_null = 0.0014456

Likelihood (exptl hypothesis), L_expt = 9.26e-05

Bayes Factor, B = 0.064058

Prior distribution assumed for difference in probability correct is P(Delta) = exp(-0.5*x.^2/0.401709^2) .* (x>=0)

You can enter other priors in valid Matlab code.They don't need to be normalised; the program does that for you. Some examples below (hint: don't miss out the dots before the operators!)
(Don't forget the dots!) Some examples:

Example 1: Uniform (flat) prior: ones(size(x))
Example 2: Uniform with bounds: ones(size(x)) .* (x>-0.5 & x<0.5)
Example 3: Gaussian with mean=0 & SD=0.3: exp(-0.5*x.^2/0.3^2)
Example 4: Gaussian with mean=0.2 & SD=0.3: exp(-0.5*(x-0.2).^2/0.3^2)
Example 5: Half-Gaussian with SD=3: exp(-0.5*x.^2/0.3^2) .* (x>=0)
Example 6: Exponential with decay constant 0.3: exp(-x./0.3).*(x>=0)

Given data & assumptions, Delta can range from

Appendix L: **Raw Data for performance on the WWWhich task and Ancillary Tasks (10-Box Condition).**

10-Box Condition (Adults, N = 25)							Memory success scores on the WWWhich test for initial attempts (0 = No trials correct, 1 = One trial correct, 2 = Both trials correct)			RAVLT: Trial 1-5: Scores for each of the five learning trials (List A)					RAVLT: List B: Scores for immediate recall of List B	RAVLT: List A: Scores for recall of List A (post-Interference)	RAVLT: Trial 7: Scores for Delayed recall trial of List A (30 mins)	Subjective Experience of WWWhich Recall (Remember/Know)	Vividness Visual Imagery Self-Report Questionnaire	Task Contemplation Self-Report Questionnaire		Trail Making Test Response Times (RT; ms)			Stroop Colour-Word Test Response Times (RT; ms)			
Participant ID	Sex	Age (years)	Condition	Delay	Object	Testing Site	WWWhich	What-Where	What-Which	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5	List B (Interference List)	Trial 6	Trial 7	Experiential Component	Vividness Ratings	During rest break 1	During rest break 2	Trail A RT	Trail B RT	Trail AB Difference	Control (NC) RT	Experimental (NCWd) RT	Control (RCNb) RT	Experimental (RCNd) RT
2exp1a	Female	21	10-Box	60-mins	Pens	Durham University	0	0	2	8	11	15	12	15	7	12	14	Know	Vague and dim	Never	Never	41.79	34.94	6.85	50.51	72.61	27.34	27.31
3exp1a	Female	19	10-Box	60-mins	Pens	Durham University	1	0	1	11	??	14	15	14	10	10	11	Know	Moderately clear and vivid	Every now and again	Very infrequently	26.21	50.87	-24.66	60.07	82.14	31.92	33.17
4exp1a	Female	20	10-Box	60-mins	Pens	Durham University	0	1	1	5	8	12	14	13	4	12	13	Remember	Vague and dim	Very infrequently	Hardly at all	48.15	76.76	-28.61	61.11	93.28	37.39	41.81
5exp1a	Female	21	10-Box	60-mins	Pens	Durham University	0	1	2	10	15	14	15	15	11	15	15	Remember	Moderately clear and vivid	Never	Never	23.64	33.97	-10.33	68.21	95.13	30.75	35.93
6exp1a	Female	19	10-Box	60-mins	Pens	Durham University	1	1	2	11	14	15	15	15	8	15	15	Remember	Vague and dim	Never	Never	38.68	45.72	-7.04	52.88	60.79	26.93	29.14
7exp1a	Female	21	10-Box	60-mins	Pens	Durham University	0	0	2	11	12	14	14	14	7	15	15	Remember	Vague and dim	Every now and again	Hardly at all	38.03	55.76	-17.73	65.08	102.72	39.62	51.97
8exp1a	Female	21	10-Box	60-mins	Pens	Durham University	0	0	1	14	15	14	15	15	14	15	15	Remember	Vague and dim	Never	Never	34.89	59.2	-24.31	54.38	63.11	37.37	38.92
9exp1a	Female	19	10-Box	60-mins	Pens	Durham University	1	0	1	12	13	15	15	14	8	15	15	Remember	Vague and dim	Never	Every now and again	35.24	63.76	-28.52	48.04	82.9	31.43	36.77
10exp1a	Female	20	10-Box	60-mins	Pens	Durham University	1	0	0	10	15	15	15	15	10	15	15	Remember	Vague and dim	Hardly at all	Hardly at all	23.02	26.57	-3.55	43.59	45.71	31.28	39.17
11exp1a	Female	19	10-Box	60-mins	Pens	Durham University	1	0	2	8	10	14	14	15	7	14	14	Remember	Vague and dim	Very infrequently	Hardly at all	47.62	146.79	-99.17	47.82	70.08	28.65	33.41
12exp1a	Male	19	10-Box	60-mins	Pens	Durham University	0	0	1	6	10	14	13	15	9	15	14	Remember	Vague and dim	Never	Never	21.03	69.48	-48.45	51.72	68.84	28.49	32.81
13exp1a	Male	23	10-Box	60-mins	Pens	Durham University	0	1	2	6	9	12	13	14	8	13	13	Remember	Vague and dim	Never	Never	36.01	51.97	-15.96	53.75	90.71	32.29	32.42
14exp1a	Male	19	10-Box	60-mins	Pens	Durham University	0	0	2	11	15	15	14	14	12	14	15	Know	Vague and dim	Hardly at all	Never	48.56	51.25	-2.69	42.85	63.48	26.55	33.29
15exp1a	Female	20	10-Box	60-mins	Pens	Durham University	0	0	2	11	13	14	14	14	12	15	14	Remember	Vague and dim	Never	Never	20.79	39.03	-18.24	43.33	58.55	30.6	38.59
16exp1a	Female	20	10-Box	60-mins	Pens	Durham University	0	0	1	7	8	10	14	14	7	11	13	Remember	Moderately clear and vivid	Never	Never	24.17	34.48	-10.31	51.46	57.08	29	34.47
17exp1a	Female	20	10-Box	60-mins	Pens	Durham University	0	0	1	11	14	13	14	14	8	13	13	Remember	Vague and dim	Hardly at all	Hardly at all	21.13	39.35	-18.22	54.07	64.3	36.64	39.09
18exp1a	Female	19	10-Box	60-mins	Pens	Durham University	0	1	2	11	12	15	15	15	10	14	12	Remember	Vague and dim	Never	Never	21.14	39.32	-18.18	57	76.07	36.14	40.38
19exp1a	Female	19	10-Box	60-mins	Pens	Durham University	0	1	0	11	13	15	14	15	13	15	15	Remember	Vague and dim	Very infrequently	Hardly at all	28.69	69.73	-41.04	48.09	60.45	33.78	32.03
20exp1a	Female	19	10-Box	60-mins	Pens	Durham University	1	1	2	12	14	15	15	15	9	15	15	Know	Vague and dim	Never	Never	56.34	76.53	-20.19	56.16	90.2	27.89	23.69
21exp1a	Female	20	10-Box	60-mins	Pens	Durham University	0	1	2	7	9	13	13	15	8	13	8	Remember	Vague and dim	Very infrequently	Hardly at all	29.21	102.4	-73.19	51.12	64.39	32.17	37.22
22exp1a	Female	20	10-Box	60-mins	Pens	Durham University	2	0	1	5	7	10	10	13	12	12	11	Remember	Vague and dim	Very infrequently	Hardly at all	27.16	56.1	-28.94	53.49	87.26	32.4	44.52
23exp1a	Male	20	10-Box	60-mins	Pens	Newcastle University	2	2	1	11	15	15	15	15	11	15	15	Know	Moderately clear and vivid	Never	Hardly at all	24.5	41.74	-17.24	45.92	69.82	29.58	27.59
24exp1a	Female	23	10-Box	60-mins	Pens	Newcastle University	0	1	1	7	10	11	14	13	6	15	13	Remember	Vague and dim	Never	Never	31.03	43.78	-12.75	54.52	65.29	28.14	31.47
25exp1a	Male	22	10-Box	60-mins	Pens	Newcastle University	0	2	2	9	12	13	15	13	11	14	13	Remember	Moderately clear and vivid	Never	Never	32.37	52.13	-19.76	61.88	129.06	35.21	45.02
26exp1a	Male	21	10-Box	60-mins	Pens	Newcastle University	1	0	2	6	10	12	14	15	7	15	14	Remember	Moderately clear and vivid	Very infrequently	Never	43.82	56.4	-12.58	44.9	91.84	34.38	34.4

Appendix M: **Raw Data for performance on the WWWhich task and Ancillary Tasks (6-Box Condition).**

6-Box Condition (Adults, N = 25)							Memory success scores on the WWWhich test for initial attempts (0 = No trials correct, 1 = One trial correct, 2 = Both trials correct)			RAVLT: Trial 1-5: Scores for each of the five learning trials (List A)					RAVLT: List B: Scores for immediate recall of List B	RAVLT: List A: Scores for recall of List A (post-Interference)	RAVLT: Trial 7: Scores for Delayed recall trial of List A (30 mins)	Subjective Experience of WWWhich Recall (Remember/Know)	Vividness Visual Imagery Self-Report Questionnaire	Task Contemplation Self-Report Questionnaire		Trail Making Test Response Times (RT; ms)			Stroop Colour-Word Test Response Times (RT; ms)			
Participant ID	Sex	Age (years)	Condition	Delay	Object	Testing Site	WWWhich	What-Where	What-Which	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5	List B (Interference List)	Trial 6	Trial 7	Experiential Component	Vividness Ratings	During rest break 1	During rest break 2	Trail A RT	Trail B RT	Trail AB Difference	Control (NC) RT	Experimental (NCWd) RT	Control (RCNb) RT	Experimental (RCNd) RT
30	Male	19	6-Boxes	60	Toys	Newcastle University	1	2	1	10	8	13	14	14	6	13	14	Remember	Clear and reasonably vivid	Every now and again	Very infrequently	23.71	35.12	-11.41	47.87	72.22	28.72	33.78
31	Female	22	6-Boxes	60	Toys	Newcastle University	1	0	2	9	14	14	15	14	9	14	15	Remember	Moderately clear and vivid	Hardly at all	Every now and again	28.2	60.26	-32.06	77.34	92.81	46.69	55.68
32	Male	22	6-Boxes	60	Toys	Newcastle University	1	2	1	5	8	13	15	15	11	13	14	Know	Perfectly clear and as vivid as normal vision	Never	Never	36.79	64.56	-27.77	56.42	85.8	37.16	49.61
33	Female	20	6-Boxes	60	Toys	Newcastle University	1	1	1	5	9	13	12	12	6	7	8	Remember	Moderately clear and vivid	Never	Never	24.83	45.99	-21.16	52.33	79.88	33.58	36.71
34	Female	21	6-Boxes	60	Toys	Newcastle University	0	0	2	7	12	15	14	15	6	12	12	Remember	Clear and reasonably vivid	Never	Never	55.92	56.71	-0.79	42.51	65.71	36.74	37
35	Female	19	6-Boxes	60	Toys	Newcastle University	0	0	2	7	7	12	14	13	6	14	12	Remember	Clear and reasonably vivid	Every now and again	Hardly at all	34.03	46.03	-12	47.55	65.94	44.61	56.11
36	Male	22	6-Boxes	60	Toys	Newcastle University	1	0	1	9	13	15	14	14	8	12	11	Remember	Moderately clear and vivid	Never	Hardly at all	24.99	59.11	-34.12	63.58	79.77	39.35	44.28
37	Female	20	6-Boxes	60	Toys	Newcastle University	1	2	2	7	10	13	14	15	3	13	13	Remember	Moderately clear and vivid	Never	Never	31.79	57.31	-25.52	46.25	56.01	32.21	33.68
38	Female	20	6-Boxes	60	Toys	Durham University	1	0	2	11	13	15	15	15	10	15	15	Remember	Clear and reasonably vivid	Never	Never	22.65	39.71	-17.06	54.97	71.99	34.25	49.55
39	Female	21	6-Boxes	60	Toys	Durham University	1	2	2	13	15	15	15	15	12	15	15	Remember	Moderately clear and vivid	Never	Never	27.21	59.45	-32.24	60.16	73.58	26.11	32.74
40	Female	19	6-Boxes	60	Toys	Durham University	0	2	2	9	12	12	13	13	9	10	11	Remember	Clear and reasonably vivid	Never	Never	30.47	47.41	-16.94	58.9	70.45	37.48	41.45
45	Male	23	6-Boxes	60	Toys	Durham University	0	0	1	7	10	13	13	13	7	13	13	Remember	Clear and reasonably vivid	Hardly at all	Never	35.98	55.99	-20.01	58.33	67.81	36.92	49
46	Female	35	6-Boxes	60	Toys	Durham University	0	1	2	8	11	15	15	15	7	15	15	Remember	Perfectly clear and as vivid as normal vision	Never	Never	27.92	33.52	-5.6	58.17	67.47	35.14	39.94
47	Female	21	6-Boxes	60	Toys	Durham University	2	1	2	9	9	11	14	14	8	14	13	Remember	Moderately clear and vivid	Never	Never	29.28	45.1	-15.82	45.52	68.2	31.27	34.55
48	Male	31	6-Boxes	60	Toys	Durham University	0	0	1	8	13	12	14	15	7	15	15	Know	Perfectly clear and as vivid as normal vision	Never	Never	26.93	39.77	-12.84	58.46	87.47	37.35	46.32
49	Female	25	6-Boxes	60	Toys	Durham University	1	2	2	9	11	14	15	14	6	14	13	Remember	Moderately clear and vivid	Hardly at all	Hardly at all	45.4	50.72	-5.32	55.52	88.54	33.17	40.72
50	Male	23	6-Boxes	60	Toys	Durham University	1	1	2	6	10	10	13	15	8	14	15	Remember	No image at all.	Hardly at all	Hardly at all	27.3	47.81	-20.51	53.61	63.9	31.1	37.26
51	Female	19	6-Boxes	60	Toys	Durham University	1	2	2	12	14	13	15	15	11	14	15	Know	Clear and reasonably vivid	Hardly at all	Hardly at all	26.78	55.29	-28.51	54.5	59.81	32.81	30.9
52	Female	23	6-Boxes	60	Toys	Durham University	1	0	2	10	14	14	14	15	9	15	15	Know	Clear and reasonably vivid	Hardly at all	Never	38.07	47.51	-9.44	52.48	36.58	29.99	80.82
53	Female	28	6-Boxes	60	Toys	Durham University	0	0	2	6	11	13	14	15	3	15	15	Remember	Clear and reasonably vivid	Never	Never	37.77	64.67	-26.9	68.14	86.2	49.4	46.21
54	Female	26	6-Boxes	60	Toys	Durham University	1	1	2	5	7	9	10	12	5	12	12	Know	Vague and dim	Hardly at all	Hardly at all	41.58	86.76	-45.18	49.86	68.01	35.7	34.75
55	Female	22	6-Boxes	60	Toys	Durham University	0	1	2	9	14	13	14	14	4	14	13	Know	Clear and reasonably vivid	Never	Never	26.71	48.49	-21.78	57.45	75.4	36.65	56.42
56	Female	23	6-Boxes	60	Toys	Durham University	0	1	1	9	12	12	15	15	5	11	11	Remember	Clear and reasonably vivid	Very infrequently	Never	48.57	68.2	-19.63	63.45	89.66	33.34	41.89
57	Female	24	6-Boxes	60	Toys	Durham University	1	1	2	7	8	11	13	12	9	10	12	Remember	Moderately clear and vivid	Every now and again	Hardly at all	62.79	57.14	5.65	46.81	68.25	33.47	38.78
58	Female	20	6-Boxes	60	Toys	Durham University	0	1	2	8	11	12	11	12	5	11	12	Know	Clear and reasonably vivid	Never	Never	35.19	57.57	-22.38	53.58	74.14	36.51	41.69

Appendix N: Raw data table for performance on the WWWhich task and for the ancillary tasks for non-autistic children (N = 51)

Children (N = 51)								Memory success scores on the WWWhich test for initial attempts (0 = No trials correct, 1 = One trial correct, 2 = Both trials correct)			WPPSI-IV (Composite Scores) N = 51						Strength & Difficulties Questionnaire (SDQ)	Corsi-Block Test (N = 45)	Just-Noticeable Difference Task (JND)
Participant ID	Sex	Age (years)	Mental Age (months)	Condition	Delay	Object	Testing Site	WWWhich	What-Where	What-Which	Full-Scale IQ (FSIQ)	Verbal Comprehension (VCI)	Visual-Spatial Processing (VSI)	Vocabulary Acquisition (VAI)	Nonverbal Ability (NVI)	WM	Total Problem Score	Corsi Forward Span	JND Scores
BGRL0025	Male	4.87	59	6-Boxes	5-mins	Pens	School	1	1	2	90	89	94	109	90	103	8	2.8	21
BGRL0026	Male	4.53	67	6-Boxes	5-mins	Pens	School	1	1	2	140	105	138	119	146	118	5	2.6	22
BGRR0028	Female	4.7	57	6-Boxes	5-mins	Pens	School	1	1	2	104	105	88	94	106	103	8	1.4	22
DL0006	Female	4.63	66	6-Boxes	5-mins	Pens	Durham Lab	1	1	1	109	98	82	88	119	124	0	1.4	21
DL0030	Female	4.89	69	6-Boxes	5-mins	Pens	Durham Lab	0	0	2	136	139	115	104	124	121	2	2.4	23
MTA0001.37	Female	4.47	56	6-Boxes	5-mins	Pens	School	1	1	2	97	100	103	100	95	82	3	2.2	22
MTA0002.38	Male	4.47	53	6-Boxes	5-mins	Pens	School	2	1	1	110	114	106	94	99	106	11	1.8	22
MTA0003.39	Male	4.62	59	6-Boxes	5-mins	Pens	School	1	1	0	113	105	112	88	106	118	5	0	22
MTA0004.41	Female	4.55	58	6-Boxes	5-mins	Pens	School	0	0	1	103	98	117	103	107	106	5	1.4	19
MTA0006.40	Female	4.47	54	6-Boxes	5-mins	Pens	School	1	1	2	110	105	115	94	108	115	9	0	19
MTA0008.32	Female	3.74	46	6-Boxes	5-mins	Pens	School	2	0	2	110	123	100	114	99	97	5	-	13
MTA0009.33	Male	3.38	36	6-Boxes	5-mins	Pens	School	1	0	2	91	101	94	103	97	100	7	-	16
MTA0010.34	Male	3.81	40	6-Boxes	5-mins	Pens	School	1	1	0	93	94	94	100	82	75	11	-	4
MTA0011.35	Female	3.27	39	6-Boxes	5-mins	Pens	School	1	2	1	87	110	91	109	86	82	6	-	13
MTA0012.31	Female	3.93	50	6-Boxes	5-mins	Pens	School	1	2	2	107	107	109	100	100	90	0	-	10
MTA0013.36	Female	4.74	61	6-Boxes	5-mins	Pens	School	1	1	2	115	98	126	94	121	124	8	2.2	16
MTA0016.46	Male	3.04	44	6-Boxes	5-mins	Pens	School	1	0	0	97	110	85	106	81	80	9	-	13
BGRL0024	Male	5.28	65	6-Boxes	5-mins	Pens	School	1	2	2	115	108	103	103	110	121	5	1.6	19
BGRR0020	Male	5.32	69	6-Boxes	5-mins	Pens	School	2	1	2	109	114	100	100	102	85	4	2.2	20
BGRR0021	Male	5.39	56	6-Boxes	5-mins	Pens	School	2	1	2	110	117	115	109	100	106	11	1.4	19
BGRR0027	Male	5.34	57	6-Boxes	5-mins	Pens	School	1	2	2	95	100	91	91	88	90	8	1.2	19
BGRR0029	Male	5.22	65	6-Boxes	5-mins	Pens	School	1	0	1	105	100	109	109	118	121	9	1.4	19
BGY10006	Male	5.85	64	6-Boxes	5-mins	Pens	School	0	2	1	86	95	112	91	86	85	11	0.4	15
BGY10007	Female	5.58	69	6-Boxes	5-mins	Pens	School	1	1	2	104	102	126	114	104	124	9	2.6	21
BGY10009	Female	5.44	76	6-Boxes	5-mins	Pens	School	2	0	1	116	105	109	106	116	124	6	0.4	19
BGY10010	Male	5.65	76	6-Boxes	5-mins	Pens	School	1	2	1	111	111	135	97	113	109	9	1	22
BGY10011	Male	5.74	73	6-Boxes	5-mins	Pens	School	2	2	2	119	127	126	103	117	93	5	3.2	21
BGY10013	Male	5.59	67	6-Boxes	5-mins	Pens	School	2	2	1	93	98	94	97	85	106	11	2.8	20
BGY10017	Male	5.6	60	6-Boxes	5-mins	Pens	School	0	1	2	105	95	97	88	100	103	7	0.4	16
BGY10018	Male	5.48	78	6-Boxes	5-mins	Pens	School	2	2	2	113	108	115	114	119	100	2	1	21
MTA0007.42	Female	5.82	71	6-Boxes	5-mins	Pens	School	1	0	2	92	92	77	109	95	88	9	2.6	24
MTA0014.44	Male	5.66	73	6-Boxes	5-mins	Pens	School	1	2	2	95	114	100	136	91	88	5	0.4	19
N0001.47	Female	5.93	68	6-Boxes	5-mins	Pens	School	2	0	2	101	98	88	100	110	115	1	2.6	22
62S	Female	6.47	69	6-Boxes	5-mins	Pens	School	0	0	1	87	84	97	97	95	103	10	1.8	12
63S	Female	6.21	81	6-Boxes	5-mins	Pens	School	1	2	2	103	111	91	109	99	121	1	3.4	22
66S	Male	6.17	86	6-Boxes	5-mins	Pens	School	0	1	1	126	127	126	136	114	109	7	3	23
67S	Male	6.47	71	6-Boxes	5-mins	Pens	School	1	2	2	85	87	85	103	91	85	8	0.8	21
68S	Male	6.92	81	6-Boxes	5-mins	Pens	School	1	1	2	97	105	91	100	90	100	5	2.6	19
70S	Male	6.38	73	6-Boxes	5-mins	Pens	School	0	1	2	90	89	100	94	96	100	7	1.8	20
71S	Female	6.91	71	6-Boxes	5-mins	Pens	School	0	1	2	85	92	82	88	83	88	11	1.8	22
99S	Male	6.38	81	6-Boxes	5-mins	Pens	School	1	1	1	112	117	97	117	108	106	4	1.4	18
BGY10005	Male	6.13	86	6-Boxes	5-mins	Pens	School	1	0	2	106	108	126	124	119	100	5	2.6	19
BGY10008	Male	6.15	64	6-Boxes	5-mins	Pens	School	0	1	2	77	72	97	94	93	82	2	0.8	22
BGY10014	Male	6.24	74	6-Boxes	5-mins	Pens	School	0	2	2	110	105	106	91	108	115	3	0.8	17
BGY10015	Male	6.35	68	6-Boxes	5-mins	Pens	School	0	0	1	86	102	100	103	77	85	11	3.2	23
BGY10016	Female	6	74	6-Boxes	5-mins	Pens	School	0	1	2	101	102	97	91	98	103	11	3	23
MTA0005.43	Female	6.16	89	6-Boxes	5-mins	Pens	School	1	1	2	115	127	103	132	110	118	2	2.8	17
MTA0015.45	Female	6.21	72	6-Boxes	5-mins	Pens	School	1	1	2	88	89	106	117	86	93	4	0.4	19
N0003.49	Female	6.8	74	6-Boxes	5-mins	Pens	Durham Lab	0	2	1	97	92	88	94	104	82	1	1.2	18
N0003.50	Female	6.71	68	6-Boxes	5-mins	Pens	School	0	1	2	86	87	117	83	93	82	1	2.2	21
N00052	Male	6.64	78	6-Boxes	5-mins	Pens	School	2	1	2	98	100	88	111	98	97	6	3.8	19

Appendix O: Raw data table for performance on the WWWhich task and for the ancillary tasks for Autistic (N = 19) and mental-age matched Non-Autistic Children (N = 20).

Autistic (N = 19) and Mental-Aged Matched Non-Autistic (N = 20) Children									Memory success scores on the WWWhich test for initial attempts (0 = No trials correct, 1 = One trial correct, 2 = Both trials correct)			Composite Scores from WPPSI-IV (non-autistic) and WASI-II (autistic)					Corsi-Block Test (N = 45)	Just-Noticeable Difference Task (JND)	Strength & Difficulties Questionnaire (SDQ)	Social Responsiveness Scale, Second Edition (SRS-2)
Participant ID	**Group**	**Sex**	**Age (Years)**	**Mental Age (Months)**	**Condition**	**Delay**	**Object**	**Testing Site**	**WWW**	**WWhere**	**WWhich**	**FSIQ**	**Verbal Comprehension (VCI) Non-Autistic**	**Visual-Spatial Processing (VSI) Non-Autistic**	**Verbal Comprehension (VCI) Autistic**	**Perceptual Reasoning Index (PRI) Autistic**	**Corsi Forward Span**	**JND Scores**	**Total Problem Score**	**SRS-2 Total T-Scores**
53stmb	Autistic	Male	6.4	84	6-Boxes	5-mins	Pens	School 1	2	1	2	89	-	-	110	70	1.4	24	81	81
54stmb	Autistic	Male	6.9	86	6-Boxes	5-mins	Pens	School 1	1	1	2	105	-	-	95	116	2.4	16	90	90
64R	Autistic	Male	7	73	6-Boxes	5-mins	Pens	School 2	0	2	2	76	-	-	85	73	0	23	81	81
65R	Autistic	Male	7	80	6-Boxes	5-mins	Pens	School 2	1	0	1	85	-	-	79	95	2.6	23	89	89
72R	Autistic	Male	9	73	6-Boxes	5-mins	Pens	School 2	0	2	2	70	-	-	73	71	0.4	21	78	78
75R	Autistic	Male	8	70	6-Boxes	5-mins	Pens	School 2	2	1	2	70	-	-	45	65	2.2	5	76	76
76R	Autistic	Female	8	75	6-Boxes	5-mins	Pens	School 2	1	0	1	82	-	-	87	81	0	23	90	90
77TH	Autistic	Male	6.3	96	6-Boxes	5-mins	Pens	School 3	0	2	1	119	-	-	109	126	0.4	21	72	72
78TH	Autistic	Male	7.7	71	6-Boxes	5-mins	Pens	School 3	2	2	1	84	-	-	84	88	2.8	23	83	83
79TH	Autistic	Male	10	93	6-Boxes	5-mins	Pens	School 3	1	0	0	83	-	-	80	90	2	20	82	82
82ST	Autistic	Male	11.3	88	6-Boxes	5-mins	Pens	School 4	0	0	1	70	-	-	70	76	2	20	78	78
84ST	Autistic	Male	10.2	80	6-Boxes	5-mins	Pens	School 4	1	2	2	75	-	-	76	79	0.4	21	77	77
86ST	Autistic	Male	7.9	97	6-Boxes	5-mins	Pens	School 4	1	1	1	107	-	-	112	100	3.2	22	90	90
ESW52	Autistic	Male	6.7	76	6-Boxes	5-mins	Pens	School 5	1	2	1	87	-	-	81	96	1.4	21	79	79
ESW53	Autistic	Male	7.6	93	6-Boxes	5-mins	Pens	School 5	0	1	2	104	-	-	111	95	2.8	21	90	90
PSW57	Autistic	Male	8	70	6-Boxes	5-mins	Pens	School 6	0	0	0	70	-	-	45	58	0	2	77	77
PSW58	Autistic	Male	7.7	75	6-Boxes	5-mins	Pens	School 6	0	2	1	73	-	-	54	92	0	18	79	79
PSW59	Autistic	Female	7.2	77	6-Boxes	5-mins	Pens	School 6	0	0	2	76	-	-	45	92	1.4	19	89	89
SAC60	Autistic	Female	9.5	90	6-Boxes	5-mins	Pens	School 7	2	2	2	84	-	-	80	92	3.2	21	90	90
63S	Non-Autistic	Female	6.2	81	6-Boxes	5-mins	Pens	School 8	1	2	2	103	105	106	-	-	3.4	22	-	-
66S	Non-Autistic	Male	6.2	86	6-Boxes	5-mins	Pens	School 8	1	1	1	126	102	97	-	-	3	23	-	-
67S	Non-Autistic	Female	6.5	71	6-Boxes	5-mins	Pens	School 8	1	2	2	85	87	85	-	-	0.8	21	-	-
68S	Non-Autistic	Female	6.9	81	6-Boxes	5-mins	Pens	School 8	1	1	2	97	105	109	-	-	2.6	19	-	-
70S	Non-Autistic	Female	6.4	73	6-Boxes	5-mins	Pens	School 8	1	1	2	90	89	106	-	-	1.8	20	-	-
71S	Non-Autistic	Male	6.9	71	6-Boxes	5-mins	Pens	School 8	1	1	2	85	92	82	-	-	1.8	22	-	-
99S	Non-Autistic	Male	6.4	81	6-Boxes	5-mins	Pens	School 8	1	1	1	112	92	88	-	-	1.4	18	-	-
BGY10005	Non-Autistic	Female	6.1	86	6-Boxes	5-mins	Pens	School 9	1	0	2	106	100	88	-	-	2.6	19	-	-
BGY10009	Non-Autistic	Male	5.4	76	6-Boxes	5-mins	Pens	School 9	2	0	1	116	117	97	-	-	0.4	19	-	-
BGY10010	Non-Autistic	Male	5.6	76	6-Boxes	5-mins	Pens	School 9	1	2	1	111	127	103	-	-	1	22	-	-
BGY10011	Non-Autistic	Male	5.7	73	6-Boxes	5-mins	Pens	School 9	2	2	2	119	111	91	-	-	3.2	21	-	-
BGY10014	Non-Autistic	Male	6.2	74	6-Boxes	5-mins	Pens	School 9	0	2	2	110	114	100	-	-	0.8	17	-	-
BGY10016	Non-Autistic	Male	6	77	6-Boxes	5-mins	Pens	School 9	0	1	2	101	102	97	-	-	3	23	-	-
BGY10018	Non-Autistic	Male	5.5	78	6-Boxes	5-mins	Pens	School 9	2	2	2	113	127	126	-	-	1	21	-	-
MTA0005.	Non-Autistic	Male	6.2	83	6-Boxes	5-mins	Pens	School 10	1	1	2	115	111	135	-	-	2.8	17	-	-
MTA0007.	Non-Autistic	Female	5.8	71	6-Boxes	5-mins	Pens	School 10	1	0	2	92	108	115	-	-	2.6	24	-	-
MTA0014.	Non-Autistic	Male	5.7	73	6-Boxes	5-mins	Pens	School 10	1	2	2	95	105	91	-	-	0.4	19	-	-
MTA0015.	Non-Autistic	Female	6.2	72	6-Boxes	5-mins	Pens	School 10	1	1	2	88	92	77	-	-	0.4	19	-	-
N0003.49	Non-Autistic	Male	6.8	74	6-Boxes	5-mins	Pens	Durham Lab	0	2	1	97	89	100	-	-	1.2	18	-	-
N00052	Non-Autistic	Female	6.6	78	6-Boxes	5-mins	Pens	School 11	2	1	2	98	127	126	-	-	3.8	19	-	-

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