Volume I

Time and memory in autism spectrum disorder

Jonathan S Martin

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Overview

This thesis is submitted as part of the requirements for the degree of Clin.Psy.D from the School of Psychology, The University of Birmingham.

Volume I contains the research component of this thesis, consisting of a literature review, an empirical paper, and an executive summary. The literature review examines research investigating working memory in autism spectrum disorder. The aim of this review is to offer a critical examination of research investigating working memory in autism spectrum disorder, drawing together the main findings, and considering possible avenues for future research. This paper has been prepared for submission to the journal, Research in Autism Spectrum Disorders (see appendix for instructions to authors). The empirical paper describes a study examining the performance of adults with autism spectrum disorder on a test of time perception ability. The role of memory processes in time perception performance is discussed. This paper has been prepared for submission to the Journal of Autism and Developmental Disorders (see appendix for instructions to authors). Finally, the executive summary provides an overview of both the literature review and the empirical paper.

Volume II contains five clinical practice reports. The first is the case study of a man with a learning disability, suffering from anxiety and depression, and is formulated from two perspectives. The second report is a service evaluation investigating whether a community psychology team is meeting the needs of people with severe forms of learning disability. The third report is in the form of a single case experimental design, evaluating the effectiveness of an intervention to treat a simple phobia. The fourth report is a case study describing the assessment

of a man presenting with memory difficulties. The fifth report is represented by an abstract from

an orally presented case study of a boy with a chronic physical condition.

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Working memory in autism spectrum disorder

Jonathan S Martin

The University of Birmingham

Abstract

This paper reviews research investigating working memory performance in people with autism spectrum disorder (ASD). The aim of the present review is to offer a critical examination of this research, drawing together the main findings that emerge, and considering possible directions for future research. After a brief overview of the concept of working memory and it's role in human cognition, evidence relating to short-term and working memory performance in ASD is evaluated. Following a summary of the main findings in this area, the review goes on to discuss some of the limitations with the current body of research, and suggests possible avenues for future research. The paper also considers alternative accounts of cognitive task performance in ASD, and how these may relate to the findings which have been reviewed. The clinical implications of reduced working memory capacity are described, and approaches which have been designed to ameliorate these effects are discussed. The review suggests that our knowledge of working memory in ASD is still very limited, and further research addressing the methodological limitations of previous research is needed.

Memory in autism spectrum disorder (ASD) has been a focus of study for several decades, stemming from the pioneering work of Hermelin and O'Connor (1970) and influenced by early comparisons between autism and adult acquired amnesia (Boucher & Warrington, 1976). Subsequent research has not supported this comparison, but has nonetheless revealed a unique profile of memory functioning in people with ASD, highlighting relative strengths and weaknesses across several different aspects of memory (see Boucher & Bowler, 2008). One aspect of memory that has been a particular source of interest in the autism literature is *working memory*. Working memory is a limited capacity cognitive system allowing the temporary storage and manipulation of task relevant information, and is thought to play an essential role in a wide range of cognitive activities (Baddeley, 2000; Miyake & Shah, 1999; Gathercole, 1999). Measures of working memory capacity have been found to be good predictors of performance in skills such as reading comprehension, grammatical understanding, reasoning and mathematical ability (Alloway, 2006). Consequently, reduced working memory ability may have marked consequences for many aspects of everyday life. Gaining a greater understanding of working memory capability in people with ASD, offers the possibility of developing educational-based interventions to address specific difficulties that people with ASD may have (Gathercole & Alloway, 2006; Jordan, 2008). However, to date, research investigating working memory performance in ASD has inconsistent findings, with some studies finding evidence of reduced performance and others typical performance. The goal of this review is to offer a critical summary of this research, drawing together the main findings so far and highlighting the possible avenues for future research that may help improve understanding of this important cognitive structure in people with ASD.

Working Memory

The best known general model of working memory is that of Baddeley & Hitch (1974).

While there are many alternative models of this aspect of memory (see Miyake & Shah, 1999),

Baddeley and Hitch's model has been the most closely studied and has provided the framework

for a vast body of research. In its original form, Baddeley and Hitch's model comprised three

components; the central executive, the phonological loop and the visuospatial sketchpad. The

central executive is a limited capacity, domain-general system responsible for controlling

resources and monitoring information processing (Alloway, 2006). This component supervises

and coordinates two domain-specific slave systems, the phonological loop and the visuospatial

sketchpad. The former of these functions as a temporary store for verbal information which is

maintained through an articulatory rehearsal process. The latter, the visuospatial sketchpad, is

responsible for the temporary storage and manipulation of visual information. In a later revision

of the model Baddeley (2000) proposed a further slave system, the episodic buffer; a limited

capacity system capable of integrating information across the subcomponents of working

memory and long-term memory.

Working memory is often described as an *executive function*, a term used to describe a

cluster of related cognitive processes that are involved in the planning and guiding of

complicated procedures. These processes are generally agreed to include inhibition, mental

flexibility (or set-shifting), planning, and working memory (generally defined). At a neurological

level, these processes are strongly associated with the frontal lobes, and in particular the

prefrontal cortex. Early research investigating executive task ability in ASD reported reduced

levels of performance in a number of executive domains including set-shifting (e.g., Ozonoff,

Pennington, & Rogers, 1991), planning (e.g., Ozonoff & Jensen, 1999), and working memory (e.g., Bennetto, Pennington & Rogers, 1996). Such research led to the development of executive functioning accounts of ASD, which have attempted to explain some of the main characteristics of ASD in terms of executive dysfunction (Russell, 1997, Pennington et al., 1997). However, subsequent evidence for executive difficulties in ASD has been more equivocal, and a recent review by Kenworthy, Yerys, Anthony, & Wallace, 2008), argued that robust evidence for reduced performance was limited to just a few types of task: spatial working memory tasks (with strategic demands), the Wisconsin Card Sorting Task (a measure of set-shifting) and tower tasks (measures of planning). Kenworthy et al. (2008) also noted that when performance on the latter two tasks is assessed by computerised administration, the magnitude of these findings diminishes, challenging the idea that executive difficulties are a primary feature of ASD.

Measuring working memory

In the general memory literature a distinction is usually made between tasks which measure the short-term storage of information, and more complex 'executive' tasks that additionally involve the concurrent processing of that information. The former types of task are typically described as measures of *short-term memory*, while the latter types of task are described as *working memory* tasks (e.g. Conway et al., 2005; Alloway, 2006). Evidence from both the general and developmental memory literature suggests that these tasks draw upon dissociable cognitive processes (e.g. Kane et al., 2004; Alloway, Gathercole, & Pickering, 2006). However, this distinction is often not made in the ASD literature, where both types of task are often referred to as *working memory* tasks.

This review will encompass studies using both forms of task, but will apply the distinction between short-term memory and working memory tasks in order to aid a more precise understanding of the cognitive processes that may be atypical in ASD. In line with the approach often taken in the ASD literature, tasks using verbal and visuospatial stimuli will be considered separately. However, this distinction should not be construed as implying that performance on verbal and visuospatial tasks can necessarily be dissociated. Research has suggested that working memory task performance primarily reflects a domain-general ability, while short-term memory task performance is reliant upon separate domain-specific systems for verbal and visuospatial information (Kane et al., 2004). It should also be noted that working memory tasks often draw upon both verbal and visuospatial systems, making this distinction frequently irrelevant.

In the following review the term ASD will be used as a generic term to refer to people on the autism spectrum. In cases where authors have reported specific diagnoses, such as high-functioning autism (HFA) or Asperger's Syndrome (AS), these diagnostic labels will be used instead.

The current evidence

Verbal short-term memory

For a number of years, the received view in the literature has been that verbal short-term memory is intact in people with ASD, or at least commensurate with their general level of intellectual ability (Belleville, Ménard, Mottron & Ménard, 2006). Early research examining verbal memory span found unimpaired performance in individuals with ASD (e.g. O'Connor & Hermelin, 1965; Hermelin & O'Connor, 1967, 1970), although some of these early studies had

methodological limitations, such as comparing samples equated on digit span before testing

short-term memory for words (see Poirier & Martin, 2008). However, subsequent research has

supported these early findings, demonstrating intact digit span performance in higher-functioning

children and adolescents with autism (Ameli, Courchesne, Lincoln, Kaufman, & Grillon, 1988;

Rumsey & Hamburger, 1990; Bennetto et al., 1996; Williams, Goldstein, & Minshew, 2006; and

Nakahachi et al., 2006), and intact serial word recall in lower functioning children with autism

(Russell, Jarrold and Henry, 1996). However, recent evidence has suggested that individuals with

higher-functioning ASD may show reduced performance on some tests of short-term memory.

Poirier & Martin (2008) reported impaired adult ASD performance (relative to an IQ matched

comparison group) on a serial verbal recall task. While the ASD group recalled on average an

equivalent number of words as the comparison group, they made significantly more order errors-

i.e. recalling a list item, but in the wrong list position.

Further evidence of atypical short-term memory performance was provided by Alloway,

Rajendran & Archibald (2009) who examined memory performance in children with a range of

neurodevelopmental disorders: Specific Language Impairment, Developmental Coordination

Disorder, Attention-Deficit/Hyperactivity Disorder (ADHD), and 10 children with AS. A

computerised battery of memory tests was administered, which included three tests of verbal

short-term memory: digit recall, word recall, and nonword recall- each requiring participants to

recall items in the correct order. A composite measure of these tasks indicated reduced verbal

short-term memory performance in the AS group. These recent findings suggest that individuals

with ASD may have a reduced short-term memory capacity to the extent that the to-be-

remembered items must be recalled in the correct order, a finding which may relate to evidence

of atypical temporal processing in ASD (Boucher, 2001; Martin, Poirier, & Bowler, 2010).

However, it is currently unclear how these more recent findings relate to the earlier studies which found no evidence of poorer performance. Some of the earlier studies employed short-term memory measures from neuropsychological test batteries, which due to their brevity may not have been sensitive enough to reveal more subtle differences in performance. However, further research is clearly needed to extend and replicate these recent findings and explore the basis of this possible difference in performance.

Verbal Working Memory

One of the most commonly used approaches to measuring working memory capacity has been through the use of complex span tasks. Such tasks combine the presentation of to-be-remembered stimuli with a secondary task, such as comprehending sentences, and are widely recognised to be both reliable and valid measures of working memory capacity (Conway et al., 2005). One of the first studies to use complex span tasks in ASD research was conducted by Bennetto et al. (1996), who examined memory performance in a group of 19, 11-25 year olds with HFA and a comparison group of 19 participants with a variety of disorders (primarily dyslexia). A battery of tests was administered, including two verbal working memory tests: sentence span (participants were required to complete the last words to a set of sentences and then later recall these sequentially) and counting span (participants were required to count the number of dots presented on a set of cards and then later recall them sequentially). The HFA group demonstrated reduced performance on both measures of working memory, leading the authors to suggest that autism may be associated with a general deficit of working memory. However, other studies using similar tasks have failed to replicate these findings. Russell et al.

(1996) examined working memory performance in a group of children with autism (mean verbal mental age: 75.21 months), a group of children with moderate learning difficulties, and a group of typically developing children. Each child with autism was matched in terms of verbal mental age to a child from the other two groups. Three different capacity tasks were used: counting span, a sentence span task, and an odd-man-out task- all of which required the concurrent storage of information whilst carrying out a related cognitive task. The autism group performed equivalently to the learning disability comparison group, although both these groups were impaired in relation to the typically developing comparison group. Russell et al. (1996) argued that a difference between the autism and learning disability group would be expected if working memory was a core deficit in autism- i.e. related to the specific clinical characteristics of autism. In a more recent study by Alloway et al. (2009) no evidence of verbal working memory difficulties were found in a sample of 10 children with AS- both relative to a standardised sample and three other neurodevelopmental groups studied. The study employed two computerised complex span tasks (listening recall and counting recall) and a backwards digit span task.

Williams, Goldstein, Carpenter, and Minshew (2005) examined verbal and spatial working memory performance in a group of 24 children and adolescents with HFA, 31 adults with HFA and two age-corresponding matched comparison groups (the results from the spatial working memory tasks will be discussed later). Verbal working memory was assessed using an *n*-Back Letter Task, and either the Letter-Number Sequencing Subtest from the Wechsler Memory Scale (for adult participants), or the Number/Letter Memory Subtest from the Wide Range Assessment of Memory and Learning (for child and adolescent participants). The *N*-back Letter Task required participants to view a continuous stream of individually presented letters and decide for each item whether it matched the item a designated number of items back (either one

or two). Although the HFA and comparison groups produced equivalent error rates on this task, performance in both groups was almost at ceiling, suggesting that even in the most difficult condition (2-back) the task was not sufficiently demanding to detect differences (see Hockey & Geffen, 2004). In addition to this task, Williams et al. (2005) also found typical performance on both the Letter-Number Sequencing task (for the adult groups), and the Number/Letter Memory task (for the child/adolescent groups). This finding was further replicated by Williams et al. (2006) in a group of 38 children with HFA, and 38 individually matched typically developing children.

Short-term visuospatial memory tasks

Much of the evidence in this area has come from spatial span tasks, which typically require participants to recall a presented sequence of spatial locations. Geurts, Verte, Oosterlaan, Roeyers, and Sergeant (2004) used the Corsi block tapping task with a group of 41 children with HFA, a group of children with ADHD and a typically developing comparison group. In this task, an experimenter taps out a sequence of various blocks on a board, and the participant is required to reproduce this sequence. The HFA group in this sample had smaller average memory spans than the normal comparison group but not the ADHD group. Further evidence for reduced spatial span performance in children with ASD (relative to matched typical comparison groups) has come from both Williams et al. (2005) and Williams et al.(2006) using the Finger Windows task. In this task the examiner shows the child a card with window-like openings. The experimenter then pokes a pencil through the openings of a sequence of windows, following which the child is asked to copy this sequence with their finger. In addition to these findings, two studies have

reported reduced ASD performance on span tasks combining forwards and backwards conditions. Williams et al. (2005) found reduced adult HFA performance (relative to a normal comparison group) on a task similar to the Corsi block tapping task, but with an additional backwards span condition. This finding was replicated by Corbett, Constantine, Hendren, Rocke, & Ozonoff (2009) with a group of 18 children with high-functioning ASDs, using a computerised version of the same task. While these findings indicate ASD memory difficulties, they are hard to interpret because research has shown that these two conditions place a demand on different cognitive resources (e.g. Reynolds, 1997, Kessels, Van den Berg, Ruis & Brands, 2008). While forward span is a standard measure of short-term memory, the backwards condition additionally requires some degree of information manipulation, making it is hard to interpret whether the reduced performance reflects short-term memory difficulties, or more executive working memory processes.

In contrast to the above findings, several studies have reported typical spatial span performance in participants with ASD. Ozonoff & Strayer (2001) used another variant of the spatial span task with a group of 25 children and adolescents with HFA. In their task participants were shown an array of one, three of five shapes in various spatial locations, and then asked to recall the position of one of these shapes. The HFA group were found to perform equivalently to the comparison group, although it should be noted that the stimuli used in this study were all nameable shapes, meaning that verbal processes may have supported performance. Alloway et al. (2009) also found unimpaired performance in a group of 10 children with AS, who completed three computerised visuospatial short-term memory tasks, including a block tapping task. Finally, two studies have used the oculomotor delayed response paradigm to measure spatial memory performance. In this task participants fixate on a central location in their visual field while targets

(dots of light) are presented individually in their peripheral vision. Following a variable delay, participants are required to make saccadic eye movements to the locations of targets presented. Minshew, Luna, and Sweeney (1999) used this task with a group of 26 adolescents and adults with HFA, and 26 matched comparison participants. The saccades made by the HFA group were significantly less accurate. This finding was also replicated by Luna, Doll, Hegedus, Minshew, & Sweeney (2007) with a group of 61 participants with ASD, again with IQs in the normal range. The characteristics of this task are very different to typical short-term memory measures; the memory load in this task is very low (just one item), but the level of spatial precision required is very high. Consequently, these findings appear to highlight a different aspect of atypical memory performance in ASD, although it is not clear how they relate to the findings from more standard measures.

Visuospatial Working Memory tasks

In contrast to the inconsistent findings from studies using verbal working memory tasks, recent evidence has suggested that people with ASD perform at a lower level to matched comparison participants on spatial working memory tasks (Kenworthy et al., 2008). One of the first studies to find evidence of spatial working memory task difficulties in people with ASD was conducted by Morris et al. (1999) who compared the performance of a group of adults with AS, and two patient groups (one with frontal lobe excisions and one with temporal lobe excisions), on a computerised golf task in which participants had to predict (by pointing on the screen) which hole a golfer would putt their ball into. They found that the AS group performed at a significantly

lower level than a typical adult comparison group, at a level comparable to that of the frontal lobe excision group.

One of the most frequently used measures of working memory in the autism literature has been the Spatial Working Memory task from the Cambridge Neuropsychological Test Automated Battery (CANTAB). This is a computerised self-ordered pointing task in which participants must search to find a token hidden behind an array of four, six, or eight boxes. Once a token has been found (for a particular array of boxes), participants are required to search for another token within the same array of boxes, but are told that a token will not appear again under the same box. A set of trials consists of each box hiding a token once. In total, the task consists of four sets of trials for each condition (four, six, and eight boxes), and are presented in this fixed order. The two main scores derived from this task are between search errors- i.e. returning to a box which has already been checked, and a strategy score, which is calculated from the number of searches that start from the same location. A series of studies have found evidence of reduced ASD performance (relative to matched comparison groups) on this task. Goldberg et al. (2005) assessed 17 children with higher-functioning autism, 21 children with ADHD, and 32 typically developed comparison participants. The HFA children made significantly more between search errors than the comparison group overall, although the two groups didn't vary in terms of the strategies used. These findings were also replicated by Landa & Goldberg (2005) with a group of 19 children and young people with HFA (mean age 11), and Sinzig, Morsch, Bruning, Schmidt, & Lehmkuhl (2008) in a group of 20 high-functioning children. Steele, Minshew, Luna & Sweeney (2007) also found evidence of impaired performance in a group with HFA, although their sample included a larger age range (mean age: 14.83, range: 8-29 years). In addition to making more between search errors, the HFA group were less consistent in applying a sequential

search strategy. This finding was also replicated by Corbett et al. (2009), who examined executive functioning in 18 children with high-functioning (IQs >70) ASDs aged between 7 and 12 years.

However, not all studies have found evidence of ASD difficulties on spatial working memory tasks. Edgin & Pennington (2005) tested 24 children (mean age 11.43) with a diagnosis of HFA or AS on the spatial working memory task and found no differences to a comparison group, both in terms of between search errors and strategy score. Using a similar spatial task, Ozonoff & Strayer (2001) also found no evidence of spatial working memory difficulties in a group of 25 children and adolescents with HFA. Happé, Booth, Charlton & Hughes (2006) examined the performance of a group of 32 children with ASDs (predominantly AS), 30 children with ADHD, and 32 typically developing children on a range of executive functioning measures including the spatial working memory task. The ASD group were found to perform equivalently to the typically developing group on this task although, interestingly, when these groups were divided into young (ages 8 to 10) and old (ages 11 to 16) subgroups, the young (but not the old) ASD group performed significantly worse than the equivalent typically developing group. One interpretation of these findings is that working memory difficulties in higher-functioning individuals with ASD may lesson with age. However, the basis for such improvement is currently unclear and further research with adult participants may help to establish whether these difficulties do ameliorate with age.

In contrast to the evidence from spatial tasks, people with ASD seem to perform at typical levels on non-spatial visual working memory tasks. Geurts et al. (2004) used a non-spatial variant of the self-ordered pointing task, in which a group of children with ASD (mean age 9.4) were required to view an array of 6, 8, 10 or 12 abstract and difficult to verbalise designs which

changed position from trial to trial. The task was to point to a different item on each trial. The ASD group performed equivalently to a comparison group, although showed reduced performance on a measure of spatial short-term span (see earlier). Joseph, Steele, Meyer & Tager-Flusberg (2005) used a similar non-spatial variant of the self-ordered pointing task with a group of 24 high-functioning children with autism, but also included a verbal condition in which the stimuli were pictures of nameable objects. The ASD group performed as well as a comparison group in the non-verbal condition (as in Geurts et al., 2004), but showed reduced performance in the verbal condition when the items could be coded verbally. Joseph et al. (2005) argued that the ASD group were failing to verbally encode and rehearse items in working memory. This idea-that people with ASD may not use verbal mediation in executive control has recently received attention and will be discussed later. Further evidence of normal visuospatial working memory performance was reported by Ozonoff & Strayer (2001) using a computerised *n*-back task in which participants had to say whether a presented shape matched a shape presented either one or two trials back. No differences were found between the ASD group and either of the two comparison groups on this task. However, performance was close to ceiling in all three groups, even in the most difficult condition, leaving open the possibility that group differences may have emerged with greater task difficulty. However, more recently Alloway et al. (2009) also found no evidence of reduced performance on three computerised measures of visuospatial working memory capacity in a group of 10 children with AS.

Summary of evidence

The first sets of results considered in this review were from studies that have used tasks which measure memory for verbal information over the short-term, i.e. short-term memory tasks. The evidence from a series of studies suggests that individuals with ASD have normal short-term recall for verbal information such as digits and words (Belleville et al., 2006). However, there has been some recent evidence to suggest that in certain contexts (and when information has to be recalled in presented order) people with ASD may show a reduced level of performance (Poirier & Martin, 2008, Alloway et al., 2009). Studies which have looked at ASD performance on working memory tasks that involve executive processes have also produced inconsistent findings. Bennetto et al. (1996) reported reduced complex span performance relative to a clinical comparison group, though both Russell et al. (1996) and Alloway et al. (2009) did not. Studies using other forms of verbal working memory tasks have also failed to find evidence of reduced performance in either children or adults with HFA (Williams et al., 2005, Williams et al., 2006). However, error rates on the *n*-back task used by Williams et al. (2005) suggest that this task may not have been sufficiently demanding to detect differences. Despite the limitations and paucity of this evidence, a view has emerged that verbal working memory is typical in ASD (e.g. Williams et al., 2006), however, this conclusion appears to be somewhat premature and in need of further examination.

In contrast to the findings for verbal tasks, the evidence for reduced ASD performance on memory tasks using visuospatial stimuli has been more consistent. Several studies have reported reduced ASD performance on tasks which involve the short-term storage of spatial information (e.g. Geurts et al., 2004, Williams et al., 2005), although see Ozonoff & Strayer (2001). In addition, there is evidence that both adults (Williams et al., 2005) and children (Corbett et al., 2009) with ASD show impaired performance on spatial span tasks which include both forward and backwards span conditions, although it is not clear whether the poorer performance shown on these tasks represents difficulties at a short-term memory level or more executive level. However, a series of studies have now reported reduced ASD performance on tasks measuring spatial working memory- primarily on self-ordered pointing tasks (e.g. Morris et al., 1999; Goldberg et al., 2005; Steele et al., 2007), although see Edgin & Pennington (2005). Interestingly, performance on non-spatial (and non-verbal) working memory tasks appears to be normal, e.g. Geurts et al. (2004), suggesting that ASD difficulties are specific to spatial tasks. However, when non-spatial visual stimuli can be verbalised, there is evidence to suggest that ASD participants are unable to use inner speech to mediate their performance on such tasks (Joseph, et al., 2005).

Overall, the evidence to date appears to support an emerging view that individuals with ASD perform more poorly on tasks which measure spatial working memory (Williams et al., 2005; Steele et al., 2007; Kenworthy et al., 2008). However, it is not yet clear whether the reduced performance on spatial working memory tasks reflect difficulties at an executive level, or more specific spatial difficulties. Certainly the apparent dissociation between intact performance on spatial working memory tasks and reduced performance on verbal working memory tasks does not fit in well with current models of working memory. The executive aspects of working memory tasks, i.e. the demands they pose in terms of concurrent processing, are thought to be

controlled by domain general cognitive processes and so should be largely unaffected by stimuli type (Conway et al. 2005; Kane et al., 2005). Based upon this assumption there are several ways in which these findings can be accounted for. One possibility is that people with ASD do have reduced functioning at an executive level, but studies using verbal tasks have so far failed to consistently demonstrate this, perhaps due to their level of executive load. Currently, the evidence in this area is limited, and hence further research using well-established measures of working memory task performance are needed. An alternative possibility is that difficulties with spatial working memory tasks reflect a domain-specific spatial memory problem in people with ASD at a non-executive level. This interpretation is supported by evidence that individuals with ASD show reduced performance on spatial short-term memory tasks which do not involve major executive demands, e.g. Geurts et al. (2004), Williams et al. (2005). Furthermore, typical performance has been demonstrated on non-spatial non-verbal working memory tasks (e.g. Geurts et al., 2004). These findings appear to suggest that it is something specific about spatial processing which poses problems for people with ASD, and does not reflect differences at an executive level. However, it is also possible that the difficulty is due to some aspect of spatial memory *tasks*, rather than spatial processing per se. Kenworthy et al. (2008) point out that spatial working memory tasks typically involve strategic demands; although this is not the case for simple spatial short-term memory tasks, which people with ASD have also performed less well on.

A notable feature of many of the studies in this area has been the use of tasks taken from general neuropsychological batteries. In the case of spatial working memory tasks, much of the evidence for 'robust deficits' has come from one task, the spatial working memory task from the CANTAB neuropsychological test battery. This has limited the extent to which these finding can

be generalised. While using tasks from batteries allows easy comparisons between studies, the results do little to further develop our understanding of working memory in autism. Amongst other limitations, their necessary brevity means that they may lack sensitivity, and in some cases working memory and short-term memory tasks are conflated (as in the case of tasks which combine forward and backward span), making it difficult to understand the basis of reduced performance. Very few studies in this review have used complex span tasks, despite being some of the most widely used and well understood tasks used to measure working memory capacity (Conway et al., 2005). Another issue worthy of consideration is the impact of human versus computer administration. Kenworthy et al. (2008) note that on two executive control tasks- the Wisconsin Card Sorting Test and tower tasks, computer task administration leads to improved ASD performance, indicating that social factors in task administration are important to consider. While several studies have reported lower levels of performance on working memory tasks using human administration (e.g. Bennetto et al., 1996), evidence for poorer performance on spatial working memory tasks has come from computer-based tasks, suggesting that while possibly important, this factor cannot account for all the findings.

A final issue worthy of consideration relates to the characteristics of the participant groups used in the research in this area. In general, most studies have used samples which are typical in autism research; averaging around 14 years, and high-functioning in terms of intellectual level (Mottron, 2004). The use of lower functioning participants is notably absent, with the exception of Russell et al. (1996). In addition, relatively few studies have used adult samples. Mottron (2004) has suggested that for a true generalisation of the disorder to be captured, research must involve both low and high-functioning participants. While the inherent complexity of many working memory tasks limits the range of participants that can be used, this

is an important issue to be considered if our aim is to relate the unique behavioural characteristics of autism to underlying differences in cognitive processes. To do so, it is essential to ascertain whether reported ASD deficits are specific to ASD, or general deficits shared by other clinical conditions. To this end, careful matching of groups is essential. The standard approach taken by researchers is to match comparison groups in terms of measures of IQ. However, ASD IQ profiles are characteristically uneven relative to typically developing individuals- meaning that matching based upon composite scores is potentially imprecise. Jarrold & Brock (2004) suggest matching groups for performance on a task that shares a high overlap with the experimental task, but excludes the specific target process being investigated. Such an approach offers a precise way of matching groups, and would be relatively easy to adopt in this literature. It would also perhaps help guide research in terms of targeting the specific cognitive processes to be studied, rather than relying on more general measures.

Alternative accounts of ASD task performance

Several researchers have attempted to explain the patterns of performance shown by individuals with ASD on tests of memory in terms of a more general account of ASD performance across a range of cognitive domains. Two of these will now be discussed.

The role of inner speech

Russell, Jarrold and Hood (1999) have suggested that the impaired performance shown by individuals with ASD on a variety of executive tasks may be the result of their tendency not to engage in inner speech to regulate behaviour. Inner speech can support executive task performance through enabling the maintenance of arbitrary or novel rules which guide task performance, or (for example) through maintaining information which has been coded verbally. Inner speech has also been linked to various other important abilities which have direct relevance to autism, including 'theory of mind', self-awareness, and language development (Williams, Happe & Jarrold, 2008, Adams & Gathercole, 1995). If individuals with ASD tend not (or have a reduced ability) to use inner speech to support task performance, they may be particularly impaired on tasks where stimuli are non-verbal (such as visuospatial tasks) but can be coded verbally to support performance. The study described earlier by Joseph et al. (2005) offers support for this hypothesis. They found that children with ASD were impaired (relative to a comparison group) on a self-ordered pointing task when the stimuli could be verbalised, but not when they were non-verbal. Joseph et al. (2005) argued that in the verbal version, the ASD participants were failing to support their performance through coding and maintaining the names of the items in working memory.

Further support for this idea has come from Whitehouse, Maybery and Durkin (2006), who compared the performance of a group of children with autism and a mental-age matched comparison group on three tasks where performance is thought to be related to the use of inner speech. Evidence from these three tasks suggested that children with autism are limited in their

use of inner speech. Whitehouse et al. (2006) suggest three possible explanations for these findings; that there may be a delay in the development of inner speech in autism, people with autism may have poor awareness of how to use inner speech, or that the findings reflect a lack of inner speech in people with autism. However, the findings of Williams et al. (2008) suggest a more complex picture. They compared the ability of a group of 25 children with ASDs and a chronological and mental age matched comparison group to spontaneously use inner speech to mediate their recall from short-term memory. No differences were found between the two groups; for those children in both groups with mental ages over 7 years, phonologically similar pictorial stimuli were significantly less well-remembered than control stimuli, indicating evidence of inner speech. William's et al. suggest that the contrast between their findings and those on executive tasks which require inner speech use (Russell et al., 1999) may reflect an impoverished self-concept in ASD rather than an inability to use inner speech. Clearly, further research is needed to fully examine the nature of inner speech use differences in autism.

Task complexity

Some authors (Minshew & Goldstein, 1998, 2001, Williams et al., 2006, Steele et al., 2007) have attempted to account for the patterns of task performance shown by individuals with ASD on tests of memory and other cognitive domains in terms of a disorder of complex information processing. Minshew & Goldstein (2001) have suggested that memory impairments in ASD are due to a failure to automatically use organizing strategies or meaning to support

memory. They argue that as the complexity of a task increases (either through having a greater number of elements, or greater inherent semantic or visual complexity) successful task performance becomes increasingly dependent upon the use of organising strategies. Consequently, as task complexity increases, people with ASD are expected to perform increasingly poorly. Some support for this hypothesis can be found in the literature reviewed above. Several studies e.g. Joseph et al. (2005), Landa & Goldberg (2005), and Steele et al. (2007) have found evidence of increasing ASD memory difficulties as memory load increases. Steele et al. (2007) have suggested that previous null results in this area may require re-examination, since it is possible that some studies have used tasks which have not been sufficiently difficult to detect group differences.

However, not all aspects of ASD memory performance can easily be accounted for using this hypothesis. The hypothesised dissociation between verbal and spatial working memory task performance is hard to explain using this framework unless spatial tasks are inherently more 'complex' than verbal working memory tasks using the terms set out by Minshew & Goldstein (2001). While spatial working memory tasks, such as self-ordered pointing clearly have visual complexity, this is also shared by non-spatial variants, on which participants with ASD have performed typically (e.g. Geurts et al., 2004). It is also not clear how 'complexity' relates to distinctions between storage-only and executive memory tasks. Several studies have used tasks which have minimal executive demands yet have produced evidence of ASD impairment (e.g. Minshew et al., 1999, Geurts et al., 2004). In addition, Bowler & Gaigg (2008) have argued that it is difficult to see how 'complexity' can be dissociated from increasing quantity of information. While 'complexity' remains loosely defined, it is hard to make clear empirical predictions as to when impairment would be expected. In some ways the task complexity hypothesis is not

unrelated to ideas about the role of inner speech, in that it assumes that it is the atypical use of organising strategies in ASD that causes reduced task performance. However, it is not clear that task complexity, as defined by Minshew & Goldstein (2001) is always the main predictor of reduced ASD performance. For example, it would be hard to argue that the 'verbal' condition of the Joseph et al. (2005) task, was inherently more complex than the non-verbal condition, yet successful performance did appear to depend upon strategy use- in this case, the use of inner speech.

Clinical implications of working memory difficulties

While the evidence reviewed in this paper suggests that our understanding of working memory ability in people with ASD is far from comprehensive, it appears that people with ASD have working memory-related difficulties in at least some contexts, and that these are beyond the level which would normally be expected in typical individuals. Although our overall understanding of working memory in ASD is limited, this should not be a barrier to offering tailored support to individuals with ASD who appear to present with working memory-related difficulties. Reduced working memory capacity is associated with a number of difficulties relating to educational attainment including, high distractibility, short attention span, and poor problem-solving ability (Gathercole et al., 2008). The significance of such problems has led researchers to design and evaluate methods which may reduce the consequences of reduced working memory capacity. One such approach has been to try to remediate working memory performance through targeted training strategies. A recent study by Holmes, Dunning & Gathercole (2009a) investigated the effect of working memory training on children with low

working memory ability, and found that training sessions led to improvements in working memory task performance that were still significant at a six month follow-up. There have also been similar studies with clinical populations including, Down syndrome (e.g. Turley-Ames & Whitfield, 2003), ADHD (e.g. Holmes et al., 2009b), and recently, autism (Baltruschat et al., 2010). While some of these results have appeared promising, it is unclear to what extent the improvements reported in these studies generalise to other domains or result in clinically significant change. This may be particularly relevant in the case of people with ASD, who tend to be poor at generalising learning beyond it's original context (e.g. Plaisted, 2001). An alternative approach advocated by Gathercole & Alloway (2006) is to minimise memory-related failures in the classroom through managing memory loads. They set out a series of practical techniques in which task information can be presented in ways which reduce memory loads for children with poor working memory, and facilitate learning in classroom situations. In summary, a number of approaches are currently being developed to try to address low working memory ability in children. Currently there is very little evidence relating to children with ASD, and their effectiveness in general (in terms of clinically significant change) is still to be established. However, this is an important avenue of research, which appears to be progressing rapidly.

Conclusion

Over the course of the past 15 years of research, the status of working memory functioning in ASD has been the subject of considerable debate, with authors at various points arguing that working memory may be a core deficit in ASD (Bennetto et al., 1996), that working memory is intact in ASD (Ozonoff & Strayer, 2001), and more recently, that verbal working

memory is typical, but spatial working memory is impaired (Williams et al., 2005, Kenworthy et al., 2008). To date, the only consistent evidence for working memory difficulties in ASD has come from tasks measuring spatial working memory performance. However, the basis of such difficulties is not yet clear. Reduced ASD performance has also been reported on tasks which measure spatial short-term memory, leaving open the possibility that atypical spatial short-term memory may underlie the difficulties shown on executive-reliant working memory tasks. This idea is supported by evidence from studies using other types of working memory task, which have tended not to find comparable reduced ASD performance. Because executive processes within working memory are assumed to be domain-general, reduced performance across working memory tasks would be expected if people with ASD were impaired at this level. A further possibility is that the difficulties posed for people with ASD on spatial working memory tasks reflects specific demands of these types of task which are not primarily memory related. More general accounts of ASD task performance offer an alternative perspective on these findings. It is possible that spatial memory task performance is particularly dependent upon the use of inner speech, because such tasks do not directly engage verbal processes, unlike verbal memory tasks. If individuals with ASD tend not to use inner-speech processes to guide their performance, they may perform at a lower level on such tasks (Joseph et al., 2005, Russell et al., 1999).

Clearly, future research needs to establish the basis of the reported spatial working memory difficulties, and to this end, the shortcomings of previous work need to be addressed. The literature in this area is characterised by inconsistent conceptualisation of working memory, an overdependence on the use of tasks taken from neuropsychological batteries, and in some cases, the use of tasks which conflate short-term memory and working memory processes. These factors have contributed to the relatively limited progress which has been made in this area.

Specifically-designed tasks which make a clear distinction between short-term memory and working memory task processes are needed in order to determine the factors which underlie ASD performance. In addition, broader participant samples, both in terms of intellectual ability level and age are needed to establish the generality of these findings. By isolating the aspects of memory tasks that individuals with ASD find difficult, it may be possible to further understand the impact that these difficulties have upon the lives of people with ASD and make progress in terms of offering appropriate support and intervention.

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Temporal reproduction performance for longer durations in adults with autism spectrum disorder

Jonathan S Martin

The University of Birmingham

Abstract

Until recently, time perception in people with autism spectrum disorder (ASD) had received relatively little attention in the autism literature, despite clinical accounts commonly reporting day-to-day difficulties relating to the comprehension of time. However, several recent studies have begun to support these accounts, finding evidence that time processing may indeed be atypical in people with ASD. The present study examined temporal reproduction performance for durations from 2 to 14 seconds in a group of 16 adults with ASD and 18 closely matched comparison participants. The performance of the ASD group was characterised by reduced accuracy and greater variability than the comparison group, and there was some evidence to suggest that their time reproductions were biased towards the mean duration. It is possible that atypical memory processes and difficulties temporally regulating behaviour may underlie this pattern of performance. This study replicated previous findings of impaired temporal reproduction performance in ASD, and extended these findings to longer durations.

Autism is a relatively common neurodevelopmental disorder characterised by a triad of impairments affecting social interaction, communication and imagination (Wing & Gould, 1979). Attempts to understand the cognitive basis of these impairments has generated a wealth of research and revealed a profile of strengths and weaknesses across several cognitive domains (Dawson, 1996, Bowler, 2007). Until recently, time processing in autism has received relatively little research interest, despite several sources of evidence suggesting that people with autism spectrum disorders (ASD) may have particular difficulties relating to understanding the passing of time. Clinical accounts of people with ASD often mention difficulties in this area (Boucher, 2001). For example, Wing (1996) notes that, "The problems of time are not related to telling the time by the clock, which some people with autistic disorders are able to do well. The difficulties lie in comprehending the passage of time and linking it with ongoing activities" (p. 88). Wing (1996) relates a number of characteristic ASD behaviours to difficulties understanding time, including the need to be reassured about future events (and when they will occur), and the distress caused by unexpected changes to plans. Boucher (2001) has developed this idea further, proposing a link between time-parsing problems and two of the defining features of ASD, linguistic and creative impairments. Further relevant evidence has come from studies which have demonstrated atypical temporal processing in populations which are thought to share some degree of neurological overlap with autism, such as people with dementia (Perbal et al., 2005), older adults (Vanneste, Perbal, & Pouthas, 1999), people with schizophrenia (Davalos, Kisley, & Ross, 2003), and people with attention deficit hyperactivity disorder (ADHD, Barkley, Murphy, & Bush, 2001). Furthermore, many of the brain regions identified as being important in temporal

processing, such as the frontal cortex, hippocampus, basal ganglia, and cerebellum (Meck, 2005),

have been related to ASD impairments in other aspects of functioning.

Time perception in the normal population is measured through a wide variety of tasks (see

Grondin , 2003), although one of the most commonly used paradigms is time reproduction. In a

typical time reproduction task, participants are presented with a target interval and then asked to

reproduce it by indicating when a second interval has reached the same duration. Several authors

have argued that this type of task most closely captures an individual's sense of time (Fraisse,

1963, Barkley et al., 2001). Time reproduction performance is typically analysed in terms of

variability and accuracy. In terms of variability, performance is usually characterised by a form

of Weber's law in that individual variance in responding is proportional to the base duration.

Accuracy on time reproduction tasks sometimes conforms to Vierordt's law (1898) which

predicts that shorter durations of a given range will be overestimated, while longer durations will

be underestimated. Although the basis of this effect is still not fully understood (Lejeune &

Wearden, 2009), one of the most common explanations for this finding is that repeated

presentations of a given duration range lead participants to form a bias towards the average of

this range. An implication of this interpretation is that the 'indifference point' (the point at which

reproductions are neither overestimations nor underestimations) should be located close to the

mean of the durations. However, not all studies have supported this notion. Some authors have

argued that durations under approximately 2 to 3 seconds can be perceived as a unit, while the

reproduction of longer durations involves other memory processes (e.g. Pöppel, 2004). According

to this account performance up to approximately 2 to 3 seconds should be relatively accurate (or

slightly overestimated, due to reaction time), while performance beyond this point is

characterised by systematic underestimation (e.g. Pöppel, 2004; Noulhiane, Pouthas, & Samson,

2009). In studies where the mean of the duration range is around 2 to 3 seconds both of the interpretations outlined above are possible.

Despite a strong rationale to study time processing in people with ASD, there has been surprisingly little research in this area. The first study to investigate these abilities was conducted by Mostofsky, Goldbery, Landa & Denckla (2000) who compared the performance of a group of 11 children and adolescents with autism, with 17 age and IQ matched comparison participants on two processes related to cerebellar function, time interval judgement and procedural learning. In the time judgement task, participants were presented with 2 pairs of 50ms tones. The first pair were separated by 550ms while the second pair (presented 1000ms later) were separated by a variable interval that was either longer or shorter than the first 550ms interval. Participants had to indicate if this second pair defined an interval that was shorter or longer than the first. No group differences were found on the time interval task- the autism group performed equivalently to the matched comparison participants. A further study of cerebellar functioning in autism was conducted by Gowen & Miall (2005), with a group of 12 adults with Asperger's Syndrome (AS) and 12 matched comparison participants. They examined performance on several behavioural tests, including two auditory timing tasks: synchronization, in which a sequence of four beeps was presented and participants were required to press a button in time with the third and fourth beeps, and continuation, in which two beeps were heard and participants were required to complete a 4 beep sequence. The timing intervals between beeps ranged from 400 to 800ms. The AS group tended to judge the inter-stimulus interval as shorter, to respond earlier, and to be more variable in their responses. The authors interpreted the results as evidence of a cerebellum-focused dysfunction in people with AS, which causes a deficit in the integration of sensory signals with motor output. While these results seem to conflict with those of Mostofsky et al.

(2000), the timing tasks used in this study had a larger motor element which may have had an influence upon the relative performance of the two groups.

Both of the studies described above focused on temporal processing in the sub-second range, which is thought to be regulated by sub-cortical structures such as the basal ganglia and cerebellum (Mangels, Ivry & Shimizu, 1998). Time judgements in the seconds range are thought to be mediated by the frontal cortex and involve memory processes (Fraisse, 1984). Several studies have now investigated temporal processing in individuals with ASD using tasks with durations in the seconds range. The first of these studies was reported by Szelag, Kowalska, Galkowski, & Poppel (2004). They used a temporal-reproduction paradigm with a group of seven children (mean age, 12 years and 6 months) with high-functioning autism (HFA) and seven typically developing children. The task included an auditory and visual condition. In both conditions, a target duration was presented following which the participant had to reproduce this duration by pressing a button to stop the presentation of either a tone (auditory condition) or a visual shape (visual condition). In both cases, the following durations were used: 1, 1.5, 2, 2.5, 3, 3.5, 4, 4.5, 5, and 5.5 seconds. The HFA children were found to perform extremely poorly in both conditions, producing average interval durations of approximately 3000ms for all 10 actual durations. Individuals with HFA were also less consistent in their reproductions.

More recently, Wallace & Happé (2008) examined the performance of a group of 25 children and adolescents with ASD on tests of time estimation, production and reproduction. The ASD group in this study had full-scale IQs within the normal range, and were group matched in terms of age and IQ to a typically developing comparison group. The time estimation task required participants to estimate the duration of time (in seconds) between the experimenter saying 'go' and 'stop'. The time production task required participants to produce an interval by

saying 'go' to signal the beginning of the interval, and then 'stop' when they estimated that the specified time had elapsed. Finally, in the time reproduction task, the experimenter produced a target duration by saying 'go' and then (after a given interval) 'stop', and then asked each participant to reproduce this duration by saying 'go' and then 'stop'. The following durations were tested twice in each task: 2, 4, 12, 15, 45 seconds. All durations were measured by stopwatch. Performance was assessed through calculating a ratio score which divided a given response time by the actual time duration. Therefore, a perfect score would be 1, while scores above 1 or below 1 would indicate overestimation or underestimation respectively. The ASD group were found to perform at least equivalently to the matched comparison group on all three of the tests used, with some evidence of superior performance on the time reproduction task. Although these findings contrast greatly with those of Szelag et al. (2004), the significant methodological differences between the two studies makes them difficult to compare. In particular, the Szelag et al. (2004) study examined performance over much shorter durations, was computerised, and included fewer and younger participants, who were also not IQ matched with the comparison group.

Most recently, Martin, Poirier, & Bowler (2010), examined temporal reproduction performance in a group of 20 adults with ASD, and 20 age and IQ matched comparison participants. They used a time reproduction task very similar to the auditory condition of the Szelag (2004) study, using the following seven time intervals: 0.5, 1.1, 1.7, 2.3, 2.9, 3.5, and 4.1 seconds, each presented six times. The ASD group made reproductions that were significantly further from the base durations than the comparison group, and this difference increased with greater duration. In addition, individuals with ASD were significantly more variable in their responses. Both of the groups tended to overestimate shorter durations and underestimate longer

durations, although this effect was more pronounced in the ASD group. This pattern appeared to be an instance of Vierordt's law (1868), which as described earlier, predicts that shorter durations of a given range will be overestimated, while longer durations will be underestimated. Martin et al. (2010) suggested that the greater bias towards the mean shown by individuals with ASD may have been because recent episodes were less well maintained in short-term memory. This idea is consistent with recent evidence of reduced short-term memory performance in adults with ASD (Poirier & Martin, 2008). If the most recent episode (i.e. the duration to be reproduced) is not as easy to discriminate from previous episodes, prototypical representations (based upon the mean of the durations presented) will influence recall more heavily. The role of memory processes in time reproduction performance has also been demonstrated in other populations, including older adults and people with ADHD. Barkley et al. (2001) examined time reproduction performance in a group of 104 adults with ADHD. The ADHD group performed equivalently to a comparison group for shorter intervals, but became less accurate as durations increased, making significantly shorter reproductions. Barkley et al. (2001) suggested that this pattern of performance may represent a reduced capacity to retain time intervals in working memory. This interpretation is consistent with the findings of Baudouin, Vanneste, Pouthas, & Isingrini (2006) who found that working memory capacity predicted temporal reproduction performance in older adults. The older adults in this study tended to underestimate their reproductions, which the authors interpreted in terms of a reduced ability to store internal timing pulses in memory.

To date, research investigating temporal processing in people with ASD has shown that in certain experimental contexts, people with ASD perform significantly less well than typical comparison participants. However, the nature of this atypical performance remains unclear. The main aim of the present study was to examine time reproduction performance in adults with ASD

over longer time intervals than have previously been studied. One of the notable findings of Martin et al. (2010) was that the performance of the ASD group appeared to get worse (relative to the comparison group) as duration length increased. If accuracy does decline over longer durations (perhaps relating to memory load), gaining an understanding of the magnitude of this impairment is important in terms of gauging the associated clinical consequences. Studying time reproduction over longer periods arguably offers a better model of the temporal processing demands of the day-to-day environment (Wallace & Happé (2008).

This study adopts the same methodology as the study by Martin et al. (2010), but assesses whether similar patterns of performance (in terms of accuracy and variability) are replicated when longer intervals are used. The patterns of performance found in the current study may also help to distinguish between two different memory-based accounts of impaired temporal reproduction performance in adults with ASD. The ASD group in the study by Martin et al. (2010) became less accurate (displayed greater underestimation), relative to the comparison group, as duration length increased beyond the indifference point at approximately 2 seconds. If this pattern is attributable to reduced memory capacity in ASD (as similar findings have been interpreted in other populations, e.g. Barkley et al., 2001; Baudouin et al., 2006), the ASD group should show a pattern of increasing underestimation relative to the comparison group as durations (and therefore memory load) increase beyond the shortest duration (2 seconds) in the present study. On the other hand if temporal durations are less well maintained in memory in people with ASD (making ASD participants more biased towards prototypic representations (Martin et al., 2010)), the greater tendency towards overestimation of shorter durations and underestimation of longer durations should be reproduced across the longer duration range assessed in the present study. This would result in an indifference point (between overestimation and underestimation)

occurring close to the mean. It is expected that the reproductions of the comparison group will be less biased towards the mean, and show a pattern of increasing underestimation as durations lengthen, consistent with several similar studies in the typical adult literature (e.g. Kagerer, Wittmann, Szelag & Steinbüchel, 2001; Elbert, Ulrich, Rockstroh, & Lutzenberger, 1991).

Method

16 adults with ASD (13 male, and 3 female) and 18 typically developing adults (15 male, 3 female) took part in this experiment. Participants were group matched on Full-Scale IQ as measured by the WAIS-III^{UK} (The Psychological Corporation, 2000) and did not differ on Performance IQ, Verbal IQ or age. Details of age and psychometric scores are given in Table 1. All individuals with ASD were diagnosed by experienced clinicians through either the National Health Service or private clinics. All had diagnoses prior to their involvement in this research, and a review of available medical records and/or assessment with the Autism Diagnostic Observation Schedule (ADOS; Lord et al. 1989) confirmed that all met DSM-IV (American Psychiatric Association, 2000) criteria for Autism Spectrum Disorder. The ASD group were recruited through an advertisement for participants on an ASD charity website and from a database of participants who had previously taken part in research at the university. The typically developing group were recruited through an advert in a local newspaper, and from a database of previous participants. A brief interview with all participants ensured that there was no history of neuropathology or psychiatric illness, and none of the participants were currently taking psychoactive medication. Participants were paid standard University fees of £7 per hour for their participation.

The sample size selected in this study was based upon the results of a power analysis using the data of Martin et al. (2010), who employed a very similar methodology and design to the present experiment. In accordance with the general recommendations of Cohen (1992), the power analysis was conducted with an alpha level of 0.05% and a beta error level of 20%, equating to an 80% probability of detecting a relationship where one exists. The power analysis

was based upon two of the variables measured by Martin et al. (2010); accuracy (based upon the average absolute difference between the target duration and the reproduced duration), and variation (based upon the mean coefficient of variation: standard deviation/mean reproduction at a given base duration x 100). The effect sizes for these variables (in terms of Cohen's d) were 1.33 and 0.89 respectively, both indicating large effects (Cohen, 1992). The analysis revealed that a sample size of 7 in each group would be needed to detect a difference between the two groups in terms of accuracy, while a sample size of 16 would be needed to detect a group difference in terms of variation. Based upon this analysis it was decided that a minimum sample size of 16 in each group was necessary.

Table 1.

Chronological ages and IQ scores for the ASD and comparison group

| | ASD (N= 16) | | Comparison (N= 18) | |
	Mean	SD[a]	Mean	SD
Age (years)	40.7	12.9	40.4	12.6
VIQ[b]	109.2	10.3	110.4	13.7
PIQ[c]	108.7	15.6	108.9	13.8
FIQ[d]	109.6	12.5	110.5	14.2

[a] **Standard deviation**
[b] **Verbal IQ**
[c] **Performance IQ**
[d] **Full-Scale IQ**

Materials

A computer program was designed using Authorware version 7 (Macromedia, 2007) to conduct the experiment on a standard Hewlett Packard PC-compatible laptop computer. Participants responded using an external mouse device. The Authorware system clock has a 1ms resolution and has been found to have high accuracy and stability measuring event times (McGraw, Tew, & Williams, 2000). The auditory stimulus was a pure tone of 200Hz frequency, presented through the built-in speakers on the computer. Before the experiment commenced, each participant was presented with a sample tone and asked if they could hear it adequately. In addition each participant was asked if they would like to adjust the volume of the tone. None of the participants felt this was necessary. Five different durations- lasting 2, 5, 8, 11, and 14 seconds were presented.

Procedure

All participants were tested individually in a quiet room. Following the successful completion of the practice trials, participants completed the experiment by themselves, with the aim of removing any bias that the experimenter's presence might induce. Two practice trials with feedback were followed by 30 experimental trials without feedback. On the practice trials participants were told whether their reproductions were too long or too short, and by how much (in seconds or fractions of seconds). The complete set of five durations was presented six times. The presentation order of the durations was randomised within each set. Each trial started with the presentation of one of the five study tones. After each study tone was presented, the word

'wait' appeared in the centre of the screen for 2000ms, after which a second tone was presented along with a button in the centre of the screen with the word 'Stop' within it. Participants were required to reproduce the study tone duration by clicking the 'stop' button when they judged that the second tone had lasted for as long as the study tone. Upon completing the experiment, participants were asked whether they had used any particular technique, such as counting to measure the elapsed intervals.

Results

Performance was examined using three measures. Two of these (absolute difference and mean judgement ratio) measured the accuracy of the average produced duration (albeit from different perspectives), while the other (mean coefficient of variation) measured the variability of performance. Each will be described further below.

Absolute difference

As a basic measure of reproduction accuracy, the mean absolute difference between the base duration and the reproduced duration was calculated. This was obtained for each participant and base duration. A two-way mixed analysis of variance (ANOVA) was used with Group (ASD vs. Comparison), and Base Duration (5 levels) as factors. There was a main effect of Base Duration $F(4,128) = 24.11$, $p < .01$, and Group, $F(1,32) = 4.62$, $p = 0.04$. However, there was not a significant interaction between Base Duration and Group $F(4,128) = 1.51$, $p = 0.20$. The group difference is shown in Fig. 1. Individuals with ASD made reproductions that were further away

on average from the durations of the comparison group, across all five target durations. However, there was no statistical evidence to suggest that inaccuracy increased (relative to the comparison group) as duration length increased.
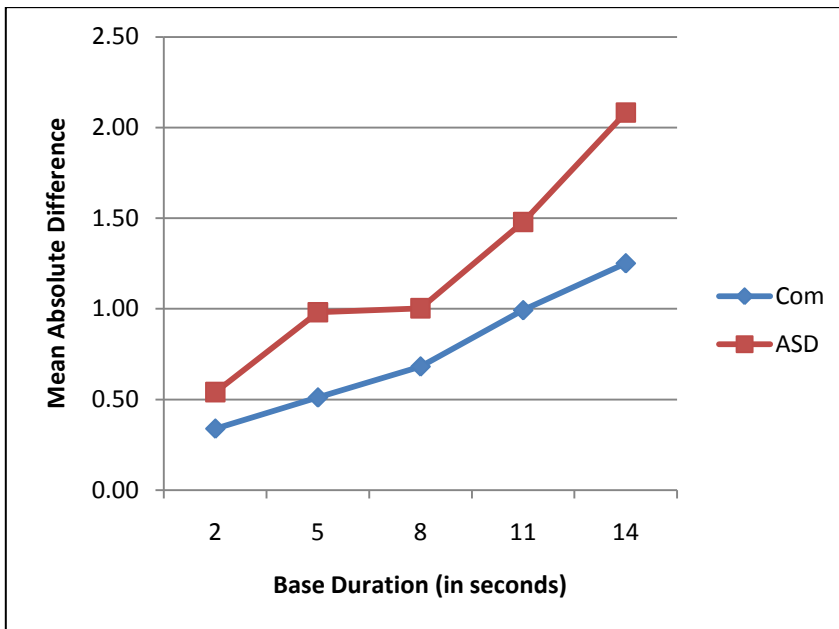

Fig. 1

The mean absolute difference between the base duration and reproduced duration at each base duration for the ASD and comparison group (Com).

Mean judgement ratio

In accordance with other studies in this area (e.g. Szelag et al., 2004, Martin et al., 2010), the mean duration judgement ratio: [(the mean reproduction interval length – base duration)/ base duration] was used as a further measure of accuracy. This measure indicates the degree to which responses are on average underestimations or overestimations of the target durations. Values above zero indicate overestimation, while negative values reflect underestimation. A two-way

mixed analysis of variance (ANOVA) was used with Group (ASD vs. Comparison), and Base Duration (5 levels) as factors. There was a significant effect of Base Duration $F(4,128) = 6.07$, $p < .01$, but not of Group. The interaction between Base Duration and Group approached significance $F(4,128) = 2.34$, $p = 0.06$, and this appears to be reflected in Fig 2. Analysing the two groups separately, there was a significant effect of Base Duration in the ASD group, $F(4,60) = 4.32$, $p < .01$, but not in the comparison group, $F(4,68) = 1.43$, $p < .24$.

The accuracy of the ASD group varied according to the duration length, showing a tendency to overestimate shorter durations, and underestimate longer durations, with their most accurate performance occurring at the mean of the durations (8 seconds). In contrast, duration length did not have a significant effect upon the accuracy of the comparison group.
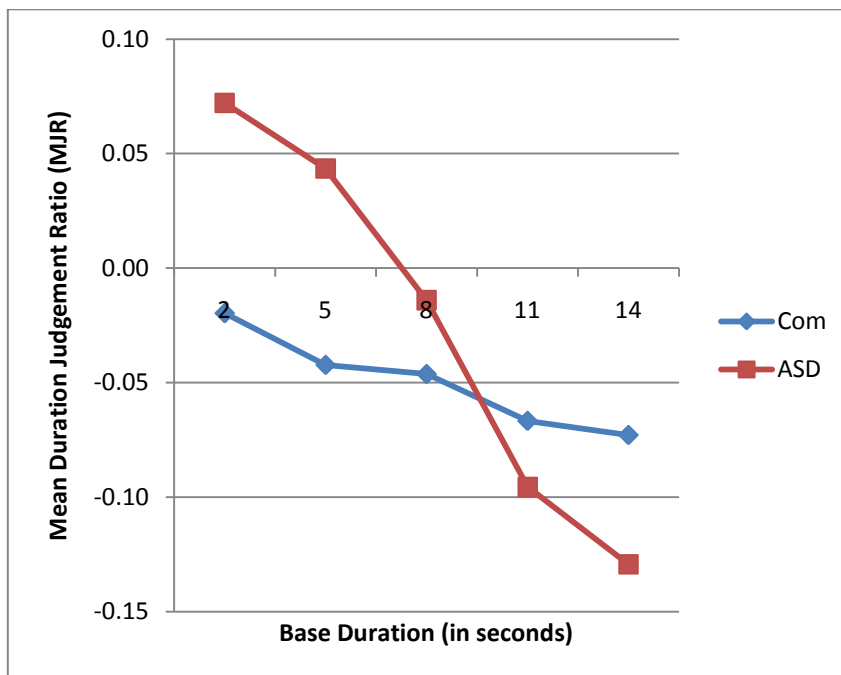

Fig. 2

The mean duration judgement ratio at each base duration for the ASD and comparison group

To investigate whether these patterns of performance developed over the course of the experiment, performance was compared between the first and last two trials of each base duration for both groups separately, see Fig 3 & 4. While Fig. 3 suggests that the pattern of responding in the ASD group shifted over trials, this was not statistically significant in either the ASD group, $F(1,15) = 1.54$, $p = 0.24$ or the comparison group $F(1,17) = 1.35$, $p = 0.26$. However, the limited number of data points and high variability (particularly in the ASD sample) weakens the power of this analysis.
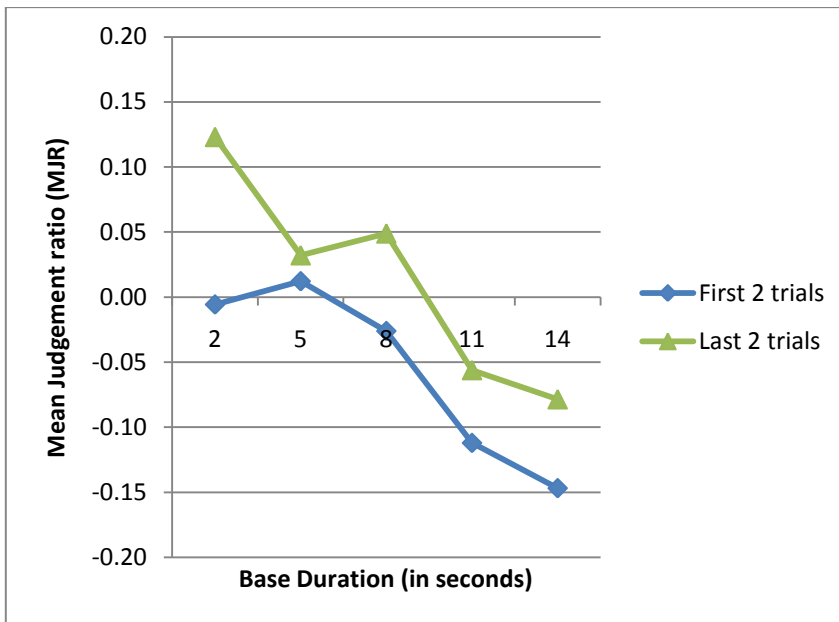
Fig. 3

The mean duration judgement ratio at each base duration for the first and last two trials in the ASD group.
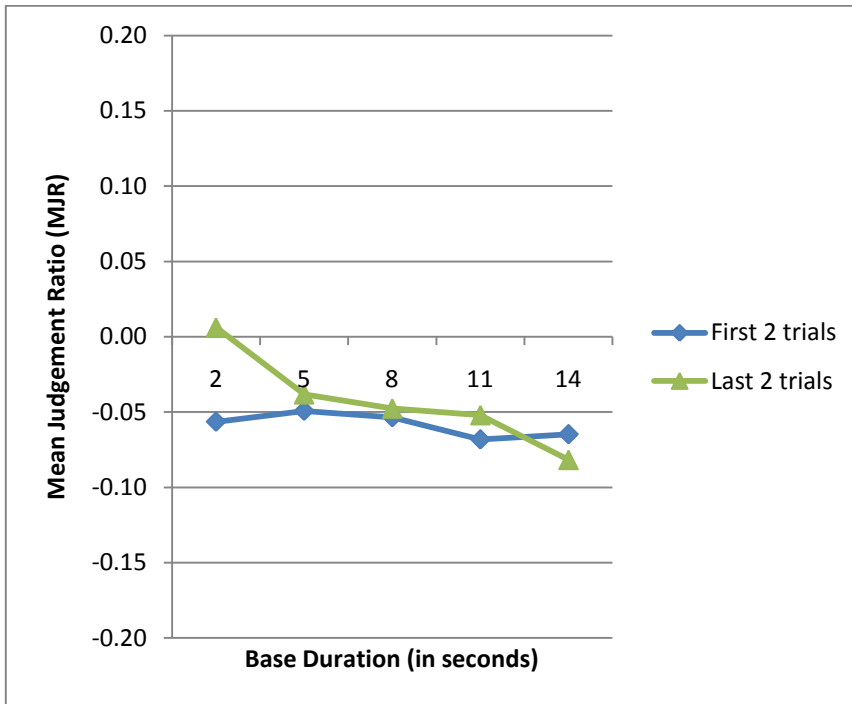
Fig. 4

The mean duration judgement ratio at each base duration for the first and last two trials in the

comparison group.

Mean coefficient of variation

In accordance with previous studies in this area (e.g. Szelag et al., 2004, Martin et al.,

2010), the mean coefficient of variation: (standard deviation/mean reproduction at a given base

duration)*100)), was used as a measure of variability in responses, with higher scores indicating

greater variability in responding. A two-way mixed analysis of variance (ANOVA) was used

with Group (ASD vs. Comparison), and Base Duration (5 levels) as factors. There was a

significant effect of Base Duration $F(4,128) = 9.66$, $p < .01$, and Group, $F(1,32) = 4.66$, $p < .04$,

but no interaction between these factors $F(4,128) = 0.46$, $p = .76$.

Fig 5. shows the mean coefficient of variation for both groups across the five target durations. Higher mean coefficient of variation values across the five durations in the ASD group indicated greater variability in responding, although the trend in responding (with reduced mean coefficient of variation values as target duration increases) was very similar in both groups, as confirmed by the non-significant interaction reported above. When asked whether they had used any particular strategy during the experiment, all participants in both groups reported counting.
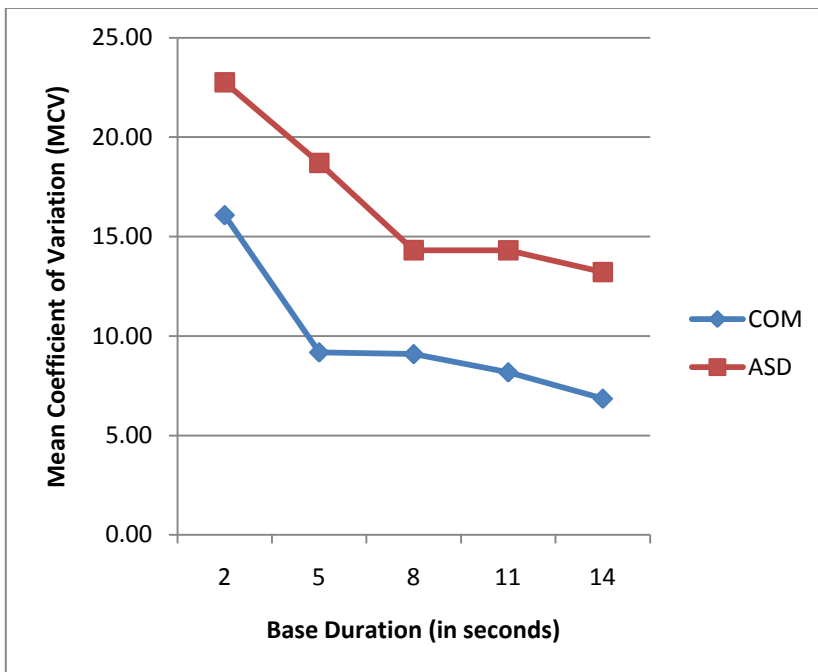
Fig. 5

The mean coefficient of variation at each base duration for the ASD and comparison group

Discussion

The main aim of the present study was to examine time reproduction performance in adults with ASD over longer time intervals. The ASD group in this study produced less accurate and more variable time reproductions than a closely matched comparison group. This was demonstrated by the ASD group's higher absolute error and coefficient of variation scores, reflecting reduced accuracy and greater variability respectively. The results from this study replicate the main findings of Martin et al. (2010), and extend evidence of reduced time perception performance in adults with ASD to longer time durations. They also support previous evidence of atypical temporal processing performance in people with ASD (e.g. Szelag et al., 2004; Gowen & Miall, 2005). Evidence that people with ASD perform less well on tasks involving time perception over longer durations are consistent with clinical reports suggesting that people with ASD have difficulties relating to the understanding of time (e.g. Wing, 1996).

A further aim of the current study was to examine whether the performance of individuals with ASD would show greater relative impairment as duration length increased. In the study by Martin et al. (2010), the ASD group showed an increasing pattern of underestimation (relative to the comparison group), as target durations increased beyond 2.3 seconds (close to the lower limit in the current study). Similar findings have been reported in other populations, and interpreted in terms of reduced memory capacity, in that as durations increase in length, a greater load is placed upon memory (e.g. Barkley et al., 2001; Baudouin et al., 2006). However, this pattern was not found in the present study. While individuals with ASD were less accurate than the comparison group, there was no evidence to suggest that they became increasingly less accurate (relative to the comparison group) as durations increased. The present findings would appear to suggest that

the impaired performance shown by the ASD group on this task does not reflect reduced memory capacity. It remains possible that this effect was negated by participants using a counting strategy in this study, or perhaps overridden by other processes acting upon performance, such as bias towards the mean. However, counting was also not controlled in the study by Martin et al. (2010) and the study by Barkley et al. (2001) with adults with ADHD, arguing against the former of these interpretations.

In the study by Martin et al. (2010) the reproductions of both groups appeared to show a bias towards the mean of the duration range, although this effect was stronger in the ASD group. In the present study there was evidence for this bias in the ASD group, but not in the comparison group. It should be noted that the interaction between group and duration length (in terms of the mean duration judgement ratio) just failed to reach significance, and hence conclusions regarding the differences between the two groups in this regard need to be supported by additional research. However, further analysis revealed that duration length had a significant effect upon the accuracy of the ASD group in this study; they tended to overestimate shorter durations, and underestimate longer durations, making almost veridical reproductions at the mean base duration (8 seconds). In contrast, duration length did not have a significant effect upon accuracy in the comparison group. The pattern of performance shown by the ASD group in this study is consistent with the findings of Martin et al. (2010) and appears to be an example of Vierordt's law (1898). Some authors have explained this effect in terms of a learning process whereby successive trials of a given duration range leads to a bias towards the mean of these durations (e.g. Noulhiane et al., 2009). Martin et al. (2010) interpreted this bias in light of recent evidence that short-term memory performance may be atypical in ASD (e.g. Martin, Poirier, Bowler & Gaigg, 2006; Poirier & Martin, 2008). They suggested that if the most recent interval is less well maintained in memory in people with

ASD (and so less easy to discriminate from previous intervals), then performance may be more biased by prototypical representations based upon the mean of previously presented intervals. An implication of this interpretation is that the bias towards the mean should emerge over the course of the experimental trials. This was assessed by comparing performance between the first and last two trials of each duration. There was some evidence of change between these two sets of trials in the ASD group (see Fig. 3), but this did not reach statistical significance. However, the limited number of data points and high variability in the ASD sample significantly reduced the power of this analysis.

In contrast to the ASD group, the accuracy performance of the comparison group in this study (in terms of the mean duration judgement ratio) was not significantly affected by duration length. The shortest duration was very slightly underestimated, and subsequent durations were progressively underestimated, although this was not a significant trend. These findings are consistent with those of several similar studies in the typical adult timing literature which have found accurate reproductions (or slight overestimation) for intervals up to 3 seconds, with systematic underestimation for durations longer than this (e.g. Kagerer et al., 2001; Elbert et al., 1991). These findings are also consistent with theoretical accounts suggesting that durations under approximately 3 seconds can be mentally perceived as a unit, while the reproduction of longer durations is dependent upon a timing mechanism which engages memory processes (e.g. Pöppel, 2004; Noulhiane et al., 2009). According to such accounts, performance up to (approximately) 2-3 seconds should be relatively accurate while performance beyond this point is characterised by systematic underestimation (e.g. Pöppel, 2004; Noulhiane et al., 2009). While the performance of the comparison participants in the current study is consistent with the evidence outlined above, their performance *prima facie* is in contrast with the findings of Martin

et al. (2010) in which the comparison group showed a similar trend to the ASD group, tending to overestimate short durations and underestimate long durations. However, if performance is compared from the point at which the durations from the two studies overlap (2 seconds), the trend in responding is markedly consistent. The performance of the comparison group in the study by Martin et al. (2010) can be explained in terms of either a bias towards the mean, *or* (in accordance with the present findings) a transition between timing systems.

Another aspect of performance analysed in this study was variation in responding. In both groups, the mean coefficient of variation declined as the length of durations increased, a pattern indicative of performance when counting is used as a strategy (Wearden, 1991). The effect of counting on time perception performance has been explored in several studies. Research has shown that counting is generally adopted as a strategy when durations extend beyond approximately 2 seconds (Grondin, Ouellet, & Roussel, 2004). While it produces similar levels of accuracy, it results in coefficients of variation which decline systematically with increasing duration length (Wearden & Lejeune, 2008). There was strong empirical evidence to suggest that in accordance with their reports, the participants in both groups counted. However, the overall levels of variability were significantly different in the two groups. Variability in the comparison group was at a level consistent with studies in the general timing literature (e.g. Gibbons & Rammsayer, 2004), whereas individuals with ASD were consistently more variable, at a level more typical of performance when not counting (Wearden, 1991). These findings suggest that while individuals with ASD used counting to regulate their timing performance, this did not reduce their variability to a level that would be typically expected of performance when counting. This finding implies that their counting performance was itself characterised by high variability. Evidence consistent with this finding was reported by Gowen & Miall (2005) who found that

their participants with AS produced more highly variable responses on a synchronisation and a continuation task, both of which require the ability to time and execute a consistent inter-stimulus interval. Sub-vocal counting is clearly a related process, although set at the pace of the individual, and involving a different motor response. It would be interesting for future research to investigate the consistency of counting in people with ASD, and also to compare time reproduction performance between counting and no counting conditions. It might also be interesting to consider the possible links with evidence concerning atypical use of inner-speech processes in the control of action in people with ASD (see Martin, 2010).

In conclusion, this study demonstrates further evidence of atypical temporal reproduction performance in adults with ASD, and extends this finding to longer durations of time. The performance of the ASD group in this study was both less accurate and more variable than a closely matched comparison group. These findings support evidence from clinical reports suggesting that people with ASD have difficulties relating to the understanding and processing of time. The longer durations used in this study serve to further highlight the possible relationship between impaired time perception and behaviour in people with ASD.

The performance of the ASD group was not characterised by decreasing accuracy (relative to the comparison group) as duration lengths increased, suggesting that their poorer performance cannot easily be explained in terms of a memory load account (e.g. Barkley et al., 2001; Baudouin et al., 2006). Instead, the ASD group tended to overestimate shorter durations and underestimate longer durations, producing their most accurate performance at the mean duration, 8 seconds. This pattern can be contrasted with the comparison group, who tended to underestimate and were not affected by duration length (in terms of the mean duration judgement ratio). It appears as though the performance of the ASD group was characterised by a bias

towards the mean duration, as was found by Martin et al. (2010). This may reflect atypical memory processes in ASD, in terms of a reduced ability to discriminate current durations from previously presented durations, making individuals with ASD more biased towards prototypical representations in memory. Consistent with several previous studies (e.g. Szelag et al., 2004; Gowen & Miall, 2005; Martin et al., 2010), individuals in the ASD group were significantly more variable in their responding. While all participants in this study reported using a counting strategy, the findings imply that the ASD group were less able to use counting to successfully regulate their performance. It is clear from the results of this study that multiple factors underlie performance on this task. Further work teasing apart these factors is necessary in order to gain a more detailed understanding of time processing in ASD. The results from this study suggests that atypical memory functioning and difficulties regulating timing behaviour may underlie the poorer performance shown by the ASD group, and are areas worthy of future investigation.

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Executive summary: Time and memory in autism spectrum disorder

Outline

This document provides an overview of the research volume of a thesis written by Jonathan Martin as part of the Doctorate in Clinical Psychology (Clin.Psy.D) training programme at the University of Birmingham. The current document summarises a literature review of research investigating working memory in autism spectrum disorders (ASD), and a research paper investigating time perception performance in adults with ASD. The term ASD is used throughout to refer to people across the autism spectrum, including diagnoses such as Asperger syndrome and high-functioning autism.

Literature review: Working Memory in Autism Spectrum Disorder

Background

Memory ability in people with ASD has been a focus of study for several decades and has revealed a pattern of relative strengths and weaknesses across several different aspects of memory (Boucher & Bowler, 2008). One particular source of interest has been working memory; a system allowing the temporary storage and manipulation of information. Working memory is thought to be essential for a wide range of everyday tasks, including language comprehension, mathematical calculations, the control of action, and planning (Baddeley, 2000). Understanding working memory ability in ASD is important both in terms of gaining a greater understanding of this condition, and also in terms of shaping educational support to this group.

Conclusions

A review of research investigating working memory performance in ASD revealed inconsistent evidence of working memory difficulties in ASD. While some studies have found evidence of impaired working memory performance (e.g. Bennetto, Pennington, & Rogers, 1996) others have not (e.g. Ozonoff & Strayer, 2001). More recently, a number of studies have reported impaired ASD performance on spatial working memory tasks, which involve the storage and manipulation of visual and non-verbal stimuli. However, the basis for this poorer performance is not well understood. It is not yet clear whether such performance reflects a working memory difficulty per se, or is more specific to spatial memory, or indeed the particular demands of spatial tasks. The lack of clarity in this area partly reflects the inconsistent definitions of working memory used in the literature, and an overreliance upon the use of tasks from neuropsychological test batteries. The review considers gaps in our knowledge in this area, and recommendations for future research.

Research paper: Temporal reproduction performance for longer durations in adults with autism spectrum disorders.

Background

ASD is a relatively common neurodevelopmental disorder thought to affect approximately 1 in a 100 people in the United Kingdom (Baird, 2006). ASDs are characterised by a triad of impairments affecting social interaction, communication and imagination (Wing &

Gould, 1979). Attempts to understand the basis of these impairments has generated a wealth of

research and revealed a profile of strengths and weaknesses across several cognitive domains,

such as memory, attention, and perception (Bowler, 2007). However, until recently very little

research has focused upon time perception in ASD, despite the fact that clinical accounts of

people with ASD often describe difficulties relating to understanding the passing of time (Wing,

1996). Several recent studies have begun to support these observations and have suggested that

time processing may indeed be atypical in people with ASD. In particular, a recent study by

Martin, Poirier & Bowler (2010) reported significantly poorer time reproduction performance in

adults with ASD over durations ranging from 0.5 to 4.1 seconds.

Aims

The aim of this study was to examine time reproduction performance in adults with ASD

over longer time intervals than have previously been studied. In addition, through adopting a

similar methodology to previous studies, the study aimed to assess whether similar patterns of

performance in terms of accuracy and variation are replicated when longer time periods are used.

Such analysis may help to determine the basis of the atypical time reproduction performance

which has been observed in people with ASD.

Method

16 adults with ASD (13 male, and 3 female) and 18 typical individuals (15 male, 3

female) took part in this experiment. Participants were group matched on Full-Scale IQ and did

not differ on Performance IQ, Verbal IQ or age. Each participant completed a computer-based

time reproduction task in which they were presented with auditory tones lasting from 2 to 14 seconds. After hearing each tone, a second tone was presented which participants were instructed to stop (by clicking the mouse) when they judged that the tone had lasted for the same length as the initial presentation. Tones lasting 2, 5, 8, 11 and 14 seconds were used, and each tone was presented 6 times.

Results

The ASD group produced reproductions which were both less accurate on average than the comparison group, and also more variable. Their performance was characterised by overestimation for shorter durations and underestimation for longer durations, with an indifference point (between overestimation and underestimation) occurring close to the mean of the presented durations- 8 seconds. In contrast the performance of the comparison group was marked by accurate performance at 2 seconds, followed by systematic underestimation as durations lengthened. The participants in both groups all reported using counting as a strategy, and performance was largely consistent with this, although the ASD group were more variable than would be expected of typical counting performance.

Conclusions

The results of this study replicate previous findings of impaired temporal reproduction performance in people with ASD (e.g. Szelag, Kowalska, Galkowski, & Poppel, 2004; Martin et al., 2010), and extend these findings to longer durations. As well as performing less accurately, the time reproductions of the ASD group showed a bias towards the mean duration of the range

sampled. They tended to overestimate shorter durations and underestimate longer durations. It is possible that this tendency reflects a short-term memory impairment in ASD. If people with ASD are less able to discriminate a given duration from previously presented durations, their responses may be more influenced by the average of the previously presented durations (Martin et al., 2010). While the majority of people in both groups reported using counting as a strategy, the ASD group produced significantly more variable performance, suggesting that this technique was less effective for them. The findings suggest that atypical memory processes and difficulties applying time-based strategies (e.g. counting) may underlie the poorer performance by people with ASD on temporal reproduction tasks. Further research using a range of timing tasks is necessary to gain a better understanding of time perception in people with ASD.

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Volume I – Appendices

The appendices are not available in the digital version of this thesis