Relational memory in children with Autism Spectrum Disorder and Reduced Language

by

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Declaration

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Abstract

Evidence from memory studies demonstrating impaired relational processing in individuals with Autism Spectrum Disorder (ASD) has most commonly been based on the learning of verbalisable material (such as lists of words) by high-functioning, verbally-able participants with ASD, who are matched to a control group on full-scale IQ scores, which limited any commentary on the universality of these difficulties across the spectrum. The current research aimed to develop a set of non-verbal tasks that test relational memory, to examine the level of this ability in children with ASD and reduced language.

It aimed to replicate some of the characteristic impairments found in relational memory in high-functioning individuals with ASD, in order to generalise these impairments to the autism spectrum as a whole. This was done by adapting behavioural paradigms which have already been used with non-human animals, and which measure relational memory non-verbally, for use with humans with and without ASD. This aimed to provide paradigms which would be suitable for all participants with ASD, and to provide more rigorous tests of relational memory in ASD, independent of the level of functioning of the individual.
The current research has shown that the paradigms adapted are effective measures of relational memory, which are suitable for use with all individuals with ASD, at any level of functioning. These findings extend the previous research demonstrating characteristic impairments in relational memory in high-functioning individuals with ASD, to include individuals with ASD who would be considered lower-functioning. They also support the view that individuals with ASD have potentially compromised hippocampal function.

Chapter 1: An overview of Autism Spectrum Disorder

1.1. History of Autism Spectrum Disorder

In the mid-1940s, the condition originally known as autism was first described in two separate accounts by separate clinicians. In the US, child psychiatrist Leo Kanner detailed the case studies of eleven children who appeared to share a pattern of behaviours which included, as he observed it: "profound aloneness", "an anxiously obsessive desire for the maintenance of sameness", and language problems, ranging from mutism to "a kind of language that does not seem intended to serve interpersonal communication" (Kanner, 1943).

Kanner explained the difficulties these children had as stemming from the "inability to relate themselves in the ordinary way to people and situations from the beginning of life" (Kanner, 1943). It was here that the now well-known term "autism" was first used, which derives from the Greek word "autos", meaning self. The author used this term to denote the fact that the children he encountered all appeared to be deeply self-absorbed. It was also useful in describing a specific disorder which displayed the characteristic symptoms that these children shared.

At around the same time in Austria, Hans Asperger, a paediatrician, published a paper in which he described patterns of behaviour in some of his patients which were similar to those of Kanner's group. In his patient group, Asperger had identified behaviours such as: lack of imaginative play, atypical communication, and behavioural problems, and labelled these behaviours "autistic psychopathy" (Asperger, 1944). At the time of writing, his findings were not widely disseminated, due mainly to his having written the paper in German, but a later account by pioneering English psychiatrist Lorna Wing described the ways in which the condition described by Asperger shared some fundamental features with that which

Kanner had previously described. For instance, both Kanner and Asperger found their patients to be uninterested in the feelings of others. There were also similarities in the way both groups used language; particularly in the impairment of language for conversation, and non-verbal forms of communication, including eye-contact (Wing, 1991).

Despite these similarities, there were also certain differences between the two groups in the way the disorder manifested itself. The group Asperger studied generally appeared not to be as challenged, and were more likely to develop some cognitive skills at a similar level to typically-developing children, such as language and communication, although these were still identified as atypical (Asperger, 1944). Identification of these important differences, along with the characteristic similarities, led to a description of autism and autistic behaviours as making up a continuum, rather than existing as discrete disorders, leading in turn to the identification of the "autism spectrum" (Wing & Gould, 1979). Therefore, behaviours on this spectrum could range from a mild manifestation - such as that described by Asperger - at one end, to a much more severe manifestation - such as Kanner-type, or "classic" autism - at the other end.

At the beginning of its discovery and classification, autism was traditionally assumed to be a childhood condition - Kanner was a child psychiatrist, Asperger a paediatrician - but as Asperger syndrome became more widely recognised, and the patient groups initially identified grew older, it started to become clear that a lot of the difficulties found to be characteristic of autism could and would persist into adulthood. Many more people began to be diagnosed with Asperger syndrome as adults; the fact that their ASD was only mildly expressed meant that it was not always spotted earlier in life. Subsequent research has tended to compartmentalise milder, or "higher-functioning" autism, and more severe, or "lower-

functioning" autism, into two discrete groups, although there are still difficulties which are common to both, expressed to a greater or lesser degree.

Kanner's identification of a syndrome was used as the basis for the development of subsequent diagnostic systems, which have been amended and refined over the years. Diagnosis of ASD is based on the observation of impairments in the domains of social interaction, communication, and repetitive behaviours (or restricted activities/interests), and current diagnostic criteria are taken from two major classification systems: the Diagnostic and Statistical Manual of Mental Disorders, fifth edition (DSM-5), and the International Classification of Diseases, Tenth Revision (ICD-10).

When the DSM was first published in 1952, the word "autism" was only used to describe one of the "psychotic reactions"; primary features of a condition then termed "schizophrenic reaction, childhood type" (DSM, 1952, p. 28). This definition did not significantly change with the second edition (DSM-II, 1968). However, the publication of the third edition brought with it the inclusion of a condition termed "infantile autism". This definition focused on the characteristics of language impairment and a "pervasive lack of responsiveness to other people" and distanced itself from its previous association with childhood schizophrenia by specifying an "absence of delusions, hallucinations" (DSM-III, 1980, p. 49). The fourth edition of the manual contained a more nuanced approach to classification. Under the general heading of "Pervasive Developmental Disorders", several disorders were incorporated as subtypes. These included: "Autistic Disorder", "Asperger Disorder", and "Pervasive Developmental Disorder, Not Otherwise Specified (including Atypical Autism)" (DSM-IV, 1994).

Diagnosis according to the criteria in the DSM-IV was based on the observation of a "triad" of impairments, including deficits in the domains of social communication, language,

and repetitive and stereotyped behaviours or interests (DSM-IV, 1994). This method of classification was dominant for many years, until the most recent revision of the manual, DSM-5, which occurred in 2013. In this edition, major changes were made to the classification of autism. All subtypes, including "Asperger Disorder" and "Pervasive Developmental Disorder, Not Otherwise Specified", were removed from the manual entirely, in favour of one defined condition known as Autism Spectrum Disorder (DSM-5, 2013).

1.2. Current methods of diagnosis and prevalence

Autism Spectrum Disorder (henceforth referred to as ASD) is a behaviourally-defined condition, diagnosed by criteria set by the ICD-10 (1992) or the DSM-5 (2013), with the most reliable diagnoses occurring after the age of approximately 2-3 years. Diagnosis according to the criteria in the DSM-5 moved away from the idea of a "triad of impairments", in favour of the observation of deficits in just two criteria: 1 - Impairments in social communication and interaction, including verbal and non-verbal forms of social communication; 2 – Restricted and repetitive patterns of behaviour, including insistence on sameness, and stereotyped motor movements. These criteria are considered more stringent, and it has been found that, since its publication, fewer people have been diagnosed with an autism spectrum disorder (Matson, Kozlowski, Hattier, Horovitz, & Sipes, 2012). The current overall prevalence of ASD in the UK is estimated to be 1.1%, with the rate among males (2%) being significantly higher than among females (0.3%) (Brugha et al., 2012).

This may have had an impact on recruitment for the current research; all participants included in the current studies were given their diagnoses before 2013. It may be that some participants may not have been given a diagnosis had they been observed according to the DSM-5. However, as all participants were recruited before the publication of the DSM-5,

they are classified as having an ASD, adhering to the criteria of the DSM-IV; reporting of the studies will reflect this.

1.3. Aetiology of Autism Spectrum Disorder

In considering the potential causes of ASD, there appears to be no consensus. The focus has shifted over the years to implicate various possible factors. In the earliest days of autism diagnosis, possibly caused in part by the fact that the earliest diagnosed patients were children, the influence of the parents was emphasised. Following his original observations of children, Kanner stated that although his view of autism was that it was an innate condition, he had noted that most of the children were being raised by parents who were emotionally unresponsive to them, potentially implying a link between their upbringing and their clinical condition (Kanner, 1949). This idea was then taken further by other theorists, most notoriously by Bruno Bettelheim, who was the most famous proponent of the "refrigerator mother" theory (Bettelheim, 1967). This view appeared to place blame squarely at the feet of the mother, postulating that autism was caused by her being emotionally "cold". This view of the cause of autism was unfortunately prevalent for several years and was very damaging to parents of autistic children. There was no evidence to support it, and the theory was eventually abandoned, although the propensity to look for environmental influences continues.

In trying to pinpoint the cause of ASD, genetic research has become particularly important. Studies of twins have been extremely useful in trying to pinpoint whether there is a genetic component to ASD. One study found that identical twins were 60% concordant for ASD, whereas in fraternal twins the concordance rate was 0% (Bailey et al., 1995), indicating strongly that ASD may be genetic disorder. However, locating the potential genetic

component of ASD would appear to be much more complicated, as many instances of autism happen spontaneously, in the absence of any family traits of ASD.

Despite the findings from genetic studies, the search for potential environmental influences has continued. Reichenberg et al. (2006) found that babies born to fathers older than the age of forty were more than five times more likely to have an ASD than babies born to fathers who were younger than thirty. More recently, it has been found that there was a higher risk of an ASD for babies of mothers aged forty and over, fathers aged fifty and over, and mothers aged twenty and under. In addition to this, the same study found that a larger age difference between the parents could increase the risk of having a child with an ASD (Sandin et al., 2016). Another risk factor for infants is having a sibling who already has ASD (Jones, Gliga, Bedford, Charman, & Johnson, 2014).

In addition to the age of the parents, environmental influences during pregnancy may play a role. Exposure to certain kinds of antidepressants in utero has been found to be associated with an increased risk of having a child with ASD (Rai et al., 2013), findings which are supported by a subsequent study that found an increased risk of ASD where selective serotonin reuptake inhibitors (SSRIs) were taken during the second and third trimesters (Boukhris, Sheehy, Mottron, & Bérard, 2016). Taken together with findings from genetic research, the current conclusion about the cause of autism is that no single cause has yet been found, with many factors playing a potential role.

1.4. Characteristics of Autism Spectrum Disorder

ASD is a typically heterogenous condition, which presents with great variability in the expression of symptoms from individual to individual. However, Wing and Gould (1979) put forward a classification system of ASD based on the quality of social interaction of the

individual, and developed the dominant idea that ASD is expressed in a triad of impairments in the domains of social, symbolic, and imaginative behaviour. Across the whole range of the spectrum people with ASD show social impairments; these difficulties may be caused in part by a difficulty in understanding the mental states of others. Experiments known as "false belief" tasks have been developed to try to measure this.

Baron-Cohen, Leslie, and Frith (1985) adapted a paradigm first devised by Wimmer and Perner (1983), in which a child is shown two characters in a visual story. One character has a marble, puts it in a certain place, and goes out of view. The other character then moves the marble to a different place. The child is then asked where, when they come back, the first character will look for the marble. The correct answer in this case would be to say where the first character believes the marble to be. Typically developing children will give the correct answer by approximately age four, whereas most children with ASD have difficulty with this task well after this age, and will give the answer of where the marble actually is, rather than where the character in the story would *believe* it is. This points to a characteristic difficulty in understanding others' mental states. People with ASD display a difficulty in understanding the representational relationship between a person's belief and the actual state of the world, and the fact that the two can be incongruent. Although able adults with ASD have been shown to have no significant deficit in this domain (Bowler, 1992), they still display difficulties in social situations which would imply problems with understanding others' beliefs, and these individuals also display difficulties in developing social relationships (Wing, 1992).

Another characteristic difficulty seen in ASD is atypical language development, although the severity of this can vary widely from person to person. Lower-functioning individuals' language development may be extremely delayed or even absent, and in the

event language does develop, can display qualities characteristic of ASD such as immediate or delayed echolalia (Tager-Flusberg & Caronna, 2007) and pronominal reversal (Lee, Hobson, & Chiat, 1994). Even when language does develop, atypicalities may still be evident, such as strange intonation and lack of reciprocity in conversation (Bowler, 2007, p. 10).

Also seen in ASD are stereotypies, which are repetitive behaviours ranging from the mild, such as placing objects in a specific order or following routines in a specific way each time, to the extreme, including behaviours such as hand-flapping. Repetitive behaviours may also be seen in higher functioning individuals with ASD in the form of restricted interests or activities, such as watching the same film or listening to the same song repeatedly (Roth, 2010, p. 83).

1.5. Comorbidity

ASD is a highly complex and heterogeneous condition, which is comorbid with several conditions. An association with epilepsy has been established, with one study finding that seizures occur in approximately 1 in 3 people with ASD (Francis, Msall, Obringer, & Kelley, 2013). Epilepsy was also found to be more common in females with ASD, with seizures typically coinciding with the onset of puberty (Canitano, 2007).

Fragile X syndrome is another condition found to be comorbid with ASD. This condition shares some of the characteristics of ASD, such as problems with communication and social interaction, including avoidance of eye contact, and repetitive behaviours. Caused by the absence of a single gene, it is estimated that around 4% of cases of Fragile X are associated with ASD (Belmonte & Bourgeron, 2006), with one study showing that 18% of

males and 9.7% of females with Fragile X syndrome met the criteria for ASD (Clifford et al., 2007).

There may also be some overlap between ASD and ADHD. During an eye-tracking task investigating the processing of gaze cues when looking at faces, atypical processing was found in children with ASD and children with ASD + ADHD, compared with children who had only ADHD, and a control group of typically-developing children (Groom et al., 2017).

1.6. Cognitive theories of Autism Spectrum Disorder

In addition to the observable behaviours already detailed, specific cognitive impairments have been found in ASD, which have given rise to cognitive theories of ASD. Much research has been focused on identifying a core cognitive deficit in ASD. Each theory aims to be able to explain the cognitive challenges of ASD under three criteria: that the particular problems should be specific, unique, and universal. These criteria have produced some problems for the theories, caused in part by the heterogeneity of ASD. However, three main theories have persisted through the years.

1.6.1. Impaired Theory of Mind

One of the most dominant cognitive theories of ASD is that of impaired "Theory of Mind". This is the term given to the ability to understand the mental states of others; it is typically measured by "false belief" tasks, as detailed earlier. Most children with ASD will fail this task whereas all typically-developing children pass it (Baron-Cohen et al., 1985; Pellicano, 2010).

This theory was influential for many years, and would appear to account for many of the problems associated with ASD. Indeed, a significant positive correlation has been found

between parent-reported symptoms of ASD, such as social communication and repetitive/restricted behaviours, and performance on Theory of Mind tasks (Jones et al., 2018).

However, there are also some issues that this theory is unable to overcome. For example, in the original study, although most of the children with ASD did fail the task, a minority of them passed it (Baron-Cohen et al., 1985), which would appear to go against the required criterion of universality. Several studies have also found impairments in false belief tasks in children with disorders distinct from ASD, including deaf children (Peterson & Siegal, 1995; 2000), which would call into question the uniqueness of the impairment in Theory of Mind for ASD.

1.6.2. Weak Central Coherence

Another theory postulated to explain the characteristic cognitive impairments in ASD is Weak Central Coherence Theory. Central coherence can be explained as the ability, when processing information, to also process the context in which the information is presented, or more colloquially to be able to "see the big picture" or the gestalt of an experience or event. Frith (2003, p. 154) postulates the theory of Weak Central Coherence; specifically, that individuals with ASD are less able to understand the context in which certain information is found. Support for this idea comes from several studies. Shah and Frith (1993) administered a block design task to young people with ASD, in which participants were shown a 2D design of blocks and were given blocks to recreate the design in 3D. The ASD group was found to be significantly better at perceiving detail in the stimuli than the comparison group; the authors concluded that this was due to an impairment in the ability to focus on the stimuli as a whole. These findings were replicated by Ehlers et al. (1997), and weak central coherence

was also found in a test of linguistic processing, in which participants with ASD were less able to use the context of a sentence to solve a task (Jolliffe & Baron-Cohen, 1999).

Despite the apparent strong support for this theory, other studies have found no impairment in ASD for tasks requiring global processing (Ozonoff, Strayer, McMahon, & Filloux, 1994; Mottron, Burack, Stauder, & Robaey (1999). Finding such as these discount the idea that weak central coherence is a universal impairment in ASD, and therefore it cannot solely explain the cognitive profile of ASD. It is possible that individuals with ASD may actually be subject to what is termed a "local bias", rather than a deficit in central coherence (Mottron, Belleville, & Menard, 1999), and this was the conclusion from a review of many studies of central coherence (Happé & Frith, 2006).

1.6.3. Executive Dysfunction Theory

Executive functioning is defined as those cognitive processes governed by the prefrontal cortex, and includes: planning of actions, mental flexibility, and the inhibition of inappropriate responses. Impairments in these abilities have typically been found in patients with damaged frontal lobes (e.g. Filley, Young, Reardon, & Wilkening, 1999), but have also been found in individuals with ASD. One such study presented young people with two tests of executive function. The first of these was a set-shifting task: stimuli were presented on-screen and participants had to choose the "correct" one. They were told there was a certain rule they could follow to be correct each time, and that they had to figure out the rule by trial and error. This arbitrary rule changed several times throughout the task, meaning that participants had to adapt to each new rule quickly to be able to continue to choose the "correct" stimulus. They were also given a planning task: participants were presented with the "goal" image of three balls in a stocking and were asked to recreate this arrangement on-screen whilst following certain rules about how they were allowed to move the balls. This

meant that they had to effectively plan their actions to be able to complete the task in the minimum number of moves. The ASD group were significantly impaired in both tasks compared to the control group (Hughes, Russell, & Robbins, 1994), highlighting potential parallels between individuals with ASD and patients with frontal lobe lesions. Findings such as these led Hill (2004) to postulate a cognitive theory of executive dysfunction in ASD, which implicated the prefrontal cortex as an important brain region in the development of ASD. This theory was supported by more recent findings from one study that found that children with ASD were also impaired in planning and set-shifting (Pellicano, 2010).

However, other researchers also administered tests of frontal lobe function to children with ASD and a control group and found comparable levels of executive functioning performance between the groups (Dawson et al., 2002). Yerys, Hepburn, Pennington, and Rogers (2007) also found intact executive functioning in children with ASD, which led to the idea that the executive functioning impairments seen in ASD may actually be caused by a secondary deficit. Findings such as these highlighted the lack of universality in executive dysfunction theory, and subsequently focused attention on other brain regions as the possible source of ASD-related deficits.

Dawson, Meltzoff, Osterling, and Rinaldi (1998) demonstrated that the severity of autistic symptoms in children with ASD was strongly correlated with performance in tasks which test the function of the medial temporal lobe (MTL), and not with tasks which test the function of the prefrontal cortex, although children with ASD demonstrate significantly diminished performance on both types of tasks. This led the authors to hypothesise that deficits in functions mediated by the prefrontal cortex may actually occur as a result of dysfunction of the MTL and its connectivity to the prefrontal cortex, rather than as a direct result of dysfunction of the prefrontal cortex itself. Linked to this theory is the demonstration

of other specific cognitive impairments in ASD, found in the study of memory processes. This area of research has received a large amount of attention in recent years, and is detailed below.

In summary, it would appear that while different cognitive accounts are able to explain different characteristics of ASD, no single theory can account for all the features of ASD (Happé, Ronald, & Plomin, 2006).

Chapter 2: Memory in Autism Spectrum Disorder

2.1. History of research

Research into the memory profile of Autism Spectrum Disorder (ASD) has been ongoing for several decades. The earliest observation of differential memory processes in ASD was seen in Kanner's original case study of children with autism, which found good rote memory skills (Kanner, 1943), supported by findings from subsequent studies (e.g. Wing, 1981). Although these initial observations appeared to point to an unimpaired memory profile in ASD, it came to be seen that there were certain memory impairments that appeared to follow a characteristic pattern. While no causal relationship has been established between memory and ASD, the study of specific memory impairments in the disorder may point the way to understanding some of the underlying cognitive processes in individuals with ASD (Boucher, Mayes, & Bigham, 2012).

2.2. Memory patterning in Autism Spectrum Disorder

Schacter and Tulving (1994, in Neath & Surprenant, 2003, p. 152) identify multiple memory systems, of which the main distinction lies between procedural memory and declarative memory. Procedural memory can best be described as that which is employed in the learning of motor skills and simple associations, whereas declarative memory is employed in the learning of verbally identifiable information. Declarative memory is similar to explicit memory, which refers to information that can be consciously accessed (Konkel & Cohen, 2009), including the episodic and semantic memory systems (Bachevalier & Vargha-Khadem, 2005). Research into memory in ASD has mainly focused on these elements of declarative memory.

In addition to the intact rote memory found in some of the earliest studies, recognition memory and cued recall have also been found to be unimpaired in ASD (e.g. Minshew & Goldstein, 2001; Williams, Goldstein, & Minshew, 2006). Examples of work in this area include Bennetto, Pennington & Rogers (1996), who found the performance of high-functioning children and adolescents with ASD on tests of short- and long-term recognition memory, and cued recall, to be equivalent to that of matched controls. Likewise, Bowler, Matthews and Gardiner (1997) found good recall in adults with ASD on a cued recall task involving memory for word-stems. Immediate memory span has also been demonstrated to be unimpaired in children with ASD (Hermelin & O'Connor, 1970).

However, there are certain memory impairments found in ASD that, whilst subtle, appear to be consistent and characteristic of the disorder. Individuals with ASD were found to perform significantly more poorly than matched controls in three measures of verbal short-term memory: digit recall, immediate serial recall of non-repeated words, and order memory for words, in which word lists were repeated with some of the items' positions in the order swapped (Poirier, Martin, Gaigg, & Bowler (2011). Boucher and Lewis (1989) found that children with ASD were impaired in carrying out instructions that were either spoken or demonstrated by the experimenter. These participants also tended to be less able to remember questions that had been previously asked. Spatial working memory, and memory for faces and family scenes, were also found to be impaired in adults with ASD, which may be seen as being related to some of the social difficulties seen in ASD (Williams, Goldstein, & Minshew, 2005). Reduced memory for socially-processed words compared with a control group matched on age and IQ has also been demonstrated (Brezis, Galili, Wong, & Piggot, 2014).

Findings from studies of free recall in ASD have produced mixed results: Boucher (1981) found comparable performance levels between participants with ASD and control participants when tested on their immediate free recall of word lists, whereas other studies have demonstrated significant deficits in free recall across a number of different types of stimuli (Boucher & Warrington, 1976; Summers & Craik, 1994; Mattison, Dando, & Ormerod, 2015).

However, other studies have found deficits in free recall "only under conditions where semantic or associative features form part of the studied material" (Bowler & Gaigg, in Boucher & Bowler, 2008, p. 332). One example of this comes from Tager-Flusberg (1991), who tested children with and without ASD on memory for lists of words that were either semantically related or unrelated to each other and found there to be a significant difference between the groups only in the semantically related condition. A further study also demonstrates this: Bowler, Matthews and Gardiner (1997) found deficits in the ability of individuals with ASD to spontaneously use category information to assist them in free recall, compared to typically-developed individuals. In addition to this, Bowler, Gaigg and Gardiner (2008b) also found that individuals with ASD engage in significantly less subjective organisation of items to aid their performance in a free recall task. Evidence of problems with associative features of stimuli also comes from research into recognition memory. Bowler, Gaigg, and Gardiner (2014) adapted a paradigm originally developed by Chalfonte and Johnson (1996), in which they presented participants with a grid displayed on a screen, containing coloured line drawings of various items in certain locations in the grid. Participants were asked to try to remember either a single feature (i.e. item, colour, or location), or a combination of those features. When compared to a matched control group, individuals with ASD showed no impairment in the recognition of the individual features but were significantly impaired in the recognition of the combinations. A subsequent review of

memory studies in ASD found that impairments such as these were significantly more pronounced in lower-functioning individuals (Boucher et al., 2012).

Impairments in autobiographical memory have also been found in ASD. Autobiographical memory can be referred to as the content of memory, with both the episodic and semantic memory systems involved in processing this content (Tulving, 2002). A case study of a high-functioning adult with ASD found a dissociation between semantic and episodic autobiographical memory. The participant displayed accurate knowledge about their own traits (termed semantic personal knowledge), whilst being impaired in their recall of the personal experience from which they were taken (episodic personal memory) (Klein, Chan, & Loftus, 1999). Subsequent studies of adults with ASD mirrored these findings: Crane and Goddard (2008) found episodic autobiographical memory (e.g. recalling the first day at school) to be impaired, whereas semantic autobiographical memory (e.g. recalling the address of one's school) was intact.

Impairments in the retrieval of specific elements of episodic autobiographical memories have also been demonstrated in ASD; these include reduced speed, specificity and coherence of memories (Goddard, Howlin, Dritschel, & Patel, 2007; Crane, Pring, Jukes, & Goddard, 2012; Crane, Goddard, & Pring, 2013; McDonnell, Valentino, & Diehl, 2017). Chaput et al. (2013) also found that fewer autobiographical memories were generated by individuals with ASD, and that those memories that were generated were significantly less detailed than those of a matched control group. Findings contrasting these have also been demonstrated: Crane, Lind, and Bowler (2012) found no difference in performance between adults with ASD and matched controls when asked to perform sentence completion tasks which assessed the generation of past and future events. Despite this, the majority of

evidence points towards a general impairment in the generation of episodic autobiographical memories.

Studies of autobiographical memory in children with ASD have demonstrated similar impairments. Goddard, Dritschel, Robinson, and Howlin (2014) found that children matched to a control group on age, IQ and verbal ability were significantly poorer at retrieving specific details of autobiographical memories. Bruck, London, Landa, and Goodman (2007) also found that children with ASD made more errors of omission when recalling autobiographical memories. Losh and Capps (2003) found that, while children with ASD were able to produce autobiographical memories (e.g. what happened on their most recent birthday) of similar length and content to those of typically-developing children, their narratives contained significantly fewer "sophisticated characteristics", such less complex syntax. Overall, it can be seen that individuals with ASD tend to produce fewer specific episodic autobiographical memories, and demonstrate less structural integration of those memories, as well as the tendency to focus on semantic details at the expense of personal details (Brezis, 2015, although see Robinson, Howlin, & Russell, 2017).

The difficulties found in episodic memory in ASD could potentially be caused by difficulties in encoding information that is self-referential. Memory for personally experienced events versus events experienced by a peer has been tested to investigate this possibility. Children with ASD were matched on verbal mental age with typically-developing children, and also with children who had moderate learning difficulties in the absence of ASD. Both control groups were found to have significantly better memory for personally-experienced events, whereas the ASD group demonstrated better memory for the events experienced by a peer (Millward, Powell, Messer, & Jordan, 2000). Findings such as these appear to suggest that the development of the self-concept is delayed in ASD, but that

high-functioning individuals are somewhat able to compensate for this by the time they reach adulthood (Lind, 2010).

Retrieval from episodic memory is generally associated with a feeling of remembering, i.e. the personal re-experiencing of an event. In contrast to this, semantic retrieval appears to be associated with the feeling of knowing rather than remembering; it is therefore dissociated from the feeling of personally re-experiencing the event in which an item was learnt. Remembering and knowing can also be described as recollection and familiarity, respectively, and both of these processes underly declarative memory. Potential impairments in these processes have also been studied extensively in ASD (Bigham, Boucher, Mayes, & Anns, 2010; Lind (2010); Boucher et al., 2012).

When adults with ASD were given a test of recognition for words, although their overall performance was not significantly different from that of a control group matched on age and IQ, it was associated more with a feeling of knowing, rather than remembering the words, indicating an impairment in recollection (Bowler, Gardiner, & Grice, 2000). This finding was replicated by Cooper et al. (2017) and Gaigg, Bowler, Ecker, Calvo-Merino, and Murphy (2015). Similar results were obtained during a "directed forgetting" task, in which adults with ASD remembered fewer words they had been instructed to remember than IQ-matched typical participants, an effect that occurred only for episodically recollected words.

This effect has also been found in studies with children. Wojcik, Moulin, and Souchay (2012) administered tests designed to measure the feeling-of-knowing, using episodic and semantic word pairs. Participants were asked at the study phase to make a prediction about whether they would subsequently remember an item. They found that children with ASD who were matched on age and IQ to typically-developing children were significantly less accurate in making predictions for the episodic materials. Also, during

three measures of recollection of contextual information, although overall memory was found to be unimpaired, adolescents with ASD were found to give fewer "remember" responses than a matched control group (Souchay, Wojcik, Williams, Crathern, & Clarke, 2013).

There is some evidence to suggest that, while there is a dissociation between recollection and familiarity in high-functioning individuals with ASD, with only recollection demonstrated to be impaired, both of these processes may be impaired in lower-functioning individuals with ASD. One study aimed to dissociate the two processes without the reliance on complex verbal instructions that make it difficult to test young children and those with intellectual difficulties, by developing several tests of recollection and familiarity. A temporal source memory task was developed in order to test the recollection of contextual information in lower-functioning participants. Sixteen everyday objects were first presented, one of which was a tube of Smarties. Participants were told beforehand that they would be asked whether each object came before or after the Smarties. They were then shown each object again, one by one, in a different order to that of the study phase and were asked each time if they had seen the object before or after the tube of Smarties. Adolescents with ASD were matched on ability with a group of typically-developing children, and were also matched on age and ability with a group of teenagers who had an intellectual disability in the absence of ASD. Participants in the ASD group displayed significantly poorer performance in this task than either of the two control groups, suggesting that success in this task is not purely dependent on the general intellectual ability of the participant. A shape recognition task was also given to test levels of familiarity in high-functioning children with ASD. Sixteen shapes were presented one after the other, and participants were asked to try to remember each one. During the test phase, participants were shown four shapes together, one of which had been previously presented during the study phase, and they were asked to choose which one they remembered. Young children with ASD were matched on verbal

ability with typically-developing children. No group differences were found, indicating intact familiarity in high-functioning individuals with ASD (Bigham et al., 2010). A replication of these paradigms was later carried out with lower-functioning children with ASD. The temporal source memory task confirmed the previous findings of Bigham et al. (2010). The test of shape recognition was carried out with adaptations to allow the testing of lower-functioning children with ASD: rather than showing all the shapes during the study phase, four shapes were shown one at a time, after which followed one test trial. This consisted of four shapes shown together, one of which had been seen during the study phase; this meant that participants were not required to hold all sixteen target shapes in memory. Their performance was found to be significantly poorer than that of a typically-developing group matched on verbal and non-verbal ability, and also a group of children with an intellectual disability in the absence of ASD (Ni Chuileann & Quigley, 2013). These two studies clearly demonstrate a dissociation between recollection and familiarity performance at the opposite ends of the spectrum.

Episodic future thinking, which can be described as the ability to imagine future experiences, both possible and impossible, is closely related to episodic memory (Atance & O'Neill, 2001). In typical development episodic future thinking is found to emerge at a similar time as episodic memory (Busby & Suddendorf 2005), and evidence from imaging studies demonstrates increased activity in similar brain regions for both processes (Okuda et al., 2003; Addis, Wong, & Schacter, 2007). Evidence that episodic future thinking is also impaired in ASD has been recently demonstrated. High-functioning adults with ASD were asked to report past events that had actually happened, as well as imagine and report potential future events. They recalled significantly fewer past events and also imagined significantly fewer potential future events than matched controls, and were more likely to report in the third-person during recall of past events (Lind & Bowler, 2010). In a further study, high-

functioning adults with ASD, matched on IQ with typical adults, were asked to describe several scenes, including fictional scenes not related to themselves (testing the ability to construct a scene), fictional but possible scenes involving themselves (testing episodic future thinking ability), and previously experienced events (testing episodic memory). They were found to be significantly impaired at each of these tasks, demonstrating the association between scene construction, episodic future thinking, and episodic memory (Lind, Williams, Bowler, & Peel, 2014). Individuals with ASD were also found to be less likely to re-experience the spatio-temporal context involved in the recollection of an episodic memory (Bowler, Gardiner & Gaigg, 2007; Ferretti et al., 2018).

An explanation for findings such as impaired episodic memory and future thinking in ASD could be that there are problems binding the disparate elements of an experience to form a coherent whole event in memory (Lind, 2010), which points to a potential deficit in ASD of *relational memory.*

2.3. Relational memory

Whenever we recall a memory of a personal experience, that memory is made up of several disparate elements specific to that experience, e.g. a cinema trip, to see Moana, on a Wednesday, in the rain, with Jonah. These individual elements are bound together to form one coherent recollection of that specific experience. Relational memory, or relational binding, can be described as the ability to bind together these disparate, episode-specific aspects of experience into configurations which can then be used in a flexible way. These relations occur accidentally within the experience as a whole, and flexible use of them enables us to recall one or other element by itself (e.g. which film, which day, who came along), or the entire experience (Konkel & Cohen, 2009; Mullally & Maguire, 2014).

2.4. Relational memory in typical development

Several studies have suggested different ages by which relational memory develops. Evidence of relational memory has been found at very early stages of typical development. Newcombe, Huttenlocher, Drummey, and Wiley (1998) carried out a study in which very young children were asked to search for a hidden object in a sandbox, sometimes with external landmarks visible. They found that children were able to learn the relations between landmarks by the age of twenty-two months. Findings from preferential looking tasks have also provided evidence of relational memory at much earlier ages. Richmond and Nelson (2009) presented nine-month old infants with pictures of three separate faces on three different backgrounds. During the test phase, these three faces were presented together on one of the previously seen backgrounds. The infants tended to look significantly longer at the face that had previously been seen on that background, indicating recognition of the relation between the face and the context on which it was presented, thereby providing evidence of an awareness of relations between an item and its context at a very early age. Another test of looking preference measured the awareness of social dominance in infants, which requires a level of awareness of the relations between individuals. Infants between ten- and thirteen-months old were shown videos of two animal puppets interacting with one another. The behaviour of the puppets displayed certain dominance relationships (e.g. hippo > bear, and bear > elephant). They were then shown another video of an interaction between puppets that had been previously seen, but not together. These interactions were either congruous (e.g. hippo > elephant) or incongruous (e.g. elephant > hippo) with the original dominance interaction that was shown. The infants looked significantly longer to the incongruous interactions, demonstrating an awareness of the dominant-subordinate relationships (Gaze, Hampton, & Lourenco, 2017).

Despite the persuasive findings from studies of infants, the bulk of evidence from behavioural tests points to later development of declarative relational memory. Rudy, Keith, and Georgen (1993) presented a test of transverse patterning to typically-developing children. The task involved learning arbitrary relations between stimuli: three pairs of stimuli were made up from three individual items, and one of the pair was reinforced, e.g. A > B, B > C, and C > A. Each element was reinforced and non-reinforced an equal number of times, meaning that success in the task required an awareness that the relations between the items could be flexible. Only children over the age of four and a half were found to be able to solve this task. Findings from the non-human literature support the view that relational processes develop fairly late. Alvarado, Malkova, and Bachevalier (2016) studied transverse patterning in macaques and found that only the older animals were able to solve all the combinations.

Studies of landmark, or place, learning have also highlighted the later development of relational memory in typical development. Overman, Pate, Moore, and Peuster (1996) presented children with several tests of place learning. Children were required to find hidden goals in a search area. They were provided with reference cues around the search area, which would aid their search if they were aware of the spatial relations between the goal and the reference cues. The authors found that children under the age of approximately seven years were less able to use this spatial relational information to be able to solve the task. Further to this, Overman, Pierce, Watterson, and Coleman (2013) presented children with another test of landmark learning. A hidden reward was placed under one of two tiles, and a landmark was placed next to the tile covering the reward. The placement of the landmark stayed constant throughout the task. Although this task was arguably less complex than the previous place learning task, the authors found that only children over the age of five were able to quickly

learn the relation between the landmark and the location of the reward to be able to solve the task.

Another paradigm that has been utilised to investigate the development of relational memory is the "oddity task". These tasks involve presenting participants with a number of visual stimuli, of which one will be different to the others, i.e. the "oddity". This task "demands response to relations among simultaneously presented stimuli" (Lipsitt & Serunian, 1963) and is therefore viewed as an effective measure of relational memory. One such study administered an oddity task to children in which they were presented with three stimuli together, two of which were identical to each other, and one which was different. A reward was hidden under the odd stimulus, and the participants were required to find it by trial and error; awareness of the relations between the odd stimulus and the two others was necessary to be able to solve the task. The authors found that children under the age of six and a half were not able to reach criterion level on this task (Overman, Bachevalier, Miller, & Moore, 1996), suggesting a protracted development for this kind of relational memory.

Other studies of relational memory have focused on the memory for combinations of elements of stimuli. Sluzenski, Newcombe and Kovacs (2006) presented four- and six-year olds with complex pictures and tested them on their memory for individual elements of the pictures, as well as for combinations of the elements. The older group displayed significantly better memory for the combinations than the younger group, suggesting that relational memory undergoes considerable developmental changes between these ages. This view is supported by subsequent work in which memory for the relations between items was measured. The performance of four- and six-year olds, and young adults was compared. Participants were presented with animations of two locations, in which an item common to both locations was paired with one unique item in each location. The participants were asked

to choose the unique item for each location, a task which required an awareness of the associations between items in a specific context. The younger group performed significantly worse than the older children and the adults, whose performance was at comparable levels. This indicates that the ability to remember relations between items develops considerably between ages four and six (Ngo, 2018). A similar paradigm was also used with children, in which the memory for one-way pairings between items was measured against the memory for two- and three-way pairings. It was found that the awareness of two- and three-way pairings increases between the ages of four and seven (Yim, Dennis, & Sloutsky, 2013). Relational memory has also been studied longitudinally. Riggins (2014) tested children's memory for facts, or their sources, or a combination of the two elements. Although memory for the individual items was found to increase linearly between the ages of four and ten, memory for combinations of facts and their sources was found to increase between the ages of five and seven, indicating a dissociation between the development of item memory and relational memory.

2.5. Relational memory in Autism Spectrum Disorder

Deficits in relational memory ability have been observed in individuals with ASD for several years. Children with "classic", or Kanner-type, autism have been observed to be less able to "encode stimuli meaningfully", manifested as the lack of ability to use semantic relatedness to aid recall (Hermelin & O'Connor, 1970, p. 129), and this early observation has been borne out by subsequent findings in both low- and high-functioning individuals.

In typical development, relational encoding is found to be beneficial for subsequent recall during incidental learning tasks: participants who are given words to learn that are either related or unrelated to each other demonstrate significantly better memory for the related words (Hunt & Einstein, 1981). However, this ability appears to be attenuated in

ASD. Bowler, Gaigg, and Gardiner (2009) administered a task of word learning, in which words were presented either randomly, or arranged in categorised hierarchies (e.g. "metals" > "rare" > "platinum") which, through the use of relational information about the words, would typically aid recall. High-functioning adults with ASD were found to be less able to use the information about the relations between the words to aid their recall.

During another study with high-functioning adults with ASD, Bowler, Gaigg and Gardiner (2008a) administered free recall and recognition memory tests to typical adults and high-functioning adults with ASD, in which participants were asked to study words inside a rectangle whilst ignoring context words presented simultaneously outside the rectangle; these context words were either semantically related or unrelated to the to-be-remembered word. On testing their memory for the context words, it was found that relatedness improved the free recall performance *only* of the typical group (although recognition memory appeared to be enhanced equally in both groups). Likewise, during a free-recall task of multiple lists of categorised words, adults with ASD showed lower levels of organisation of the words into subjective categories in order to assist their recall (Bowler, Gardiner, & Gaigg, 2010).

Significantly impaired performance in ASD was also found in two other tests of subjective organisation: the Wisconsin Card Sorting Test (WCST), and the Verbal Learning Test (VLT). During the WCST, participants were asked to sort cards into categories, such as colour, number, or shape of the items on the cards. They were not told which element on which to match, but were required to find the rule by trial and error. This rule was then subject to change without the participants being told of this. During the VLT, participants were presented with lists of words to remember, which were either unrelated nouns, or related to each other, under categories such as musical instruments, sports etc. Although they performed comparably to controls in their recall of unrelated words, adults with ASD were

significantly impaired in the WCST and in their memory for the related words of the VLT, demonstrating that they were less able to subjectively organise the information (Sumiyoshi, Kawakubo, Suga, Sumiyoshi, & Kasai (2011).

In addition to this, children with ASD were found to be less able to employ an internally generated strategy to assist them in monitoring their actions. Participants were given a test of "self-ordered pointing", during which several images were presented together on a sheet of paper. The same array was presented multiple times, and each time participants were asked to point to a different picture, whilst not pointing at the same picture more than once. When the images shown were of abstract shapes, children with ASD were found to perform at the same level as typically-developing children. However, when the images comprised easily nameable objects (such as a bird, key, or shirt), the ASD group performed at a significantly lower level than the typically-developing group, indicating that they were less likely to use an internally generated strategy to remember which pictures they had already pointed at, and therefore aid their performance (Joseph, Steele, Meyer, & Tager-Flusberg, (2005).

Adolescents and adults with ASD, although able to complete short-term memory and paired-associate learning tasks, have also been found to be impaired in other tasks in which subjective organisation of the information would facilitate success. One of these tasks was the California Verbal Learning Test (CVLT; Delis, Kramer, Kaplan, & Ober, 1987), in which the objective was to learn lists of words. Nouns were read aloud to the participant, after which they were tested on their memory for them. The words were taken from several semantic categories, although this fact was not made explicit to the participant, and words from the same category were not presented sequentially, so as to not highlight the existence of the categories. Participants with ASD were found to be significantly less able than the

control group to organise the words into categories to assist their memory (Minshew & Goldstein, 2001), indicating less of a spontaneous awareness of semantic categories. This difficulty has been demonstrated in free recall even when participants with ASD are explicitly trained in the use of the relations between the words (Smith, Gardiner, & Bowler, 2007). Furthermore, free recall of semantically unrelated items has been found to be unimpaired (Bowler, Limoges, & Mottron, 2009), indicating a selective impairment dependent on the level of relatedness of items. Likewise, when children with ASD were tested on their free recall of lists of either semantically related or unrelated words, they recalled significantly fewer related words, whereas their recall of unrelated words was comparable to that of the matched control group (Maister, Simons, & Plaisted-Grant, 2013). In contrast to this however, a study of adolescents and adults with ASD found that semantic cues led to better recall in both groups. It may be that, as this was a test of cued recall, the extra support given at both study and test was enough to improve the relational memory of the ASD group (Mottron, Morasse, & Belleville, 2001).

The difficulties with episodic memory already detailed here may also be taken as evidence of an impairment in the flexible encoding of arbitrary associations between features of a personally-experienced event. Loth, Gomez, and Happé (2011) have demonstrated this in children and adults with ASD. Participants were asked to read a story, and then inspect a visual scene containing several objects. Some of these objects were related to the story they had just read, and some of them were not. Participants with ASD were found to recall significantly fewer related objects than the matched typical group. More recently, children with ASD were found to recall fewer memories than typically-developing children, when asked to verbally recall autobiographical memories (such as a birthday party, school trip, or holiday) (Maister, Simons, & Plaisted-Grant, 2013).

Evidence is increasingly pointing towards the view that episodic memory and spatial navigation are related (Xue, 2018), and there is also evidence that these two processes share a common underlying neural basis (Chen, Leong, Honey, Yong, Norman, & Hasson, 2017; Miller et al., 2013). Impairments in spatial navigation have also been demonstrated in ASD. High-functioning adults matched with controls on age and IQ were given a task of spatial navigation within a virtual space, in which they were required to search an island displayed on-screen for hidden target objects. Individuals with ASD performed significantly more poorly on this task, and performance was significantly positively correlated with measures of Theory of Mind and episodic memory (Lind, Williams, Raber, Peel, & Bowler, 2013).

Memory for the source of a presented item can also be defined as a subsection of relational memory, in that recall of the context in which an item has been learned is necessary for success in a task. This ability has also been shown to be impaired in ASD. Bennetto, Pennington, and Rogers (1996) administered tests of temporal order memory and source memory, success in both of which depends on the awareness of the context of the information. During the temporal order memory task, participants were shown a series of stimuli one after the other. They were then shown two stimuli together and were asked one of two questions. To test recognition memory for items, they were asked which had been seen before. To test temporal order memory, they were asked which of the two had been seen more recently. The children's version of the CVLT (Delis, Kramer, Kaplan, & Ober, 1986) was used to measure source memory; analysing participants' intrusion errors from lists other than the one being currently tested provided a measure of this ability. Recognition memory for the items was found to be intact in high-functioning children and adolescents with ASD, whereas they were found to be significantly impaired at the temporal order and source memory tasks.

Source memory was also tested in adolescents and adults with two tasks of word learning. During the first task, words were presented one after the other on-screen; the participant was asked to remember each word and was also required to carry out an action along with that word, such as trying to think of another word that rhymes with it. During the test phase words were shown one at a time, and the participant was asked whether they remembered that word from the study phase (testing item recognition). If the participant said they remembered that word, they were then asked which action they did for that word (testing source memory). For the second task, words were presented either written on-screen, or spoken aloud, and participants were asked to remember each word. Participants were then asked whether they remembered each word, and if so, whether that word was originally written or spoken. High-functioning individuals with ASD displayed significantly poorer performance than that of a matched control group on both tests of source memory, although this deficit appeared to be ameliorated when the questions asked during the test phase could be answered by choosing one of multiple options (Bowler, Gardiner, & Berthollier, 2004).

Lind and Bowler (2009) also found impairments in source memory for pictures in ASD. Participants were presented with picture cards one by one and were asked to take it in turns with the experimenter to name each picture. After a delay, a recognition list was read aloud to the participant; they were asked if they had seen each picture before, thereby testing recognition memory for the items. If they answered affirmatively to a picture, they were then asked who had originally named that picture, thereby testing source memory. Children with ASD matched on age and verbal ability with a group of typically-developing children were found to be impaired in recalling who had named the pictures, in the presence of intact memory for the individual items, dissociating source memory ability from item recognition ability. Adults with ASD matched with a typical group on age and ability were also impaired when required to recall the source of previously studied common word-pairs (Cooper,

Plaisted-Grant, Baron-Cohen, & Simons, 2016). In addition to this, Ring, Gaigg, and Bowler (2015) asked adults with ASD to study pictures of rooms with objects in certain locations in each room and found significantly poorer performance when participants were asked to place each object in its original location in each room.

Source memory has also been investigated in a more "real-world" setting. Children were presented with short stories, read aloud by actors. After hearing the stories, participants were tested on their recognition for facts contained in the stories, and also for memory of the different elements of the context (e.g. the face of the actor, their clothing, the furniture, colour of the walls, nearby objects etc). Children with ASD, matched with typically-developing children on chronological and mental age, were found to have intact memory for the facts of the stories, whereas their memory for the context information was impaired, in particular their memory for faces, indicating a problem with the social aspects of context (O'Shea, Fein, Cillessen, Klin, & Schultz, 2005).

Order memory has also been found to be impaired in ASD. Bowler, Poirier, Martin, and Gaigg (2016) found adults with ASD to be impaired in the recall of the serial order of locations of presented stimuli. A grid display was presented, in which dots appeared sequentially, in a specific order. Participants were required to recall the locations and the order of the dots, by tapping on the screen in the locations and order in which they appeared. Individuals with ASD were impaired in both the recall of the locations and the order of the stimuli. In another test of order memory, participants were given a list of names of historical figures and were asked to put them in order according to a semantic sequence (chronological order), or an episodic sequence (an arbitrary order displayed on-screen). High-functioning adults with ASD were impaired only on the episodic task (Gaigg, Bowler, & Gardiner, 2014).

Although much of the discussed research points to a selective deficit in relational memory, other research presents conflicting findings. Solomon, McCauley, Iosif, Carter, and Ragland (2016) presented participants with tasks of item-specific, and relational, encoding. During the item-specific task, an image was presented, and participants were asked to make a judgement about the image (e.g. whether it is an image of a living thing). During the relational task, two images were shown together, and participants were asked to make a judgement about the relation between the two (e.g. whether one object could fit inside the other). The authors found poorer item-specific memory than relational memory in high-functioning adolescents with ASD. Similarly, Ring, Gaigg, and Bowler (2016) tested high-functioning adults with ASD using abstract shape triplets presented on-screen, testing memory for the individual shapes making up the triplets, their locations on-screen, the order of presentation, and the combination of elements. Memory for the combinations was found to be impaired, consistent with previous research; however, this study also found impaired item memory, suggesting that the complexity of the task also played a role in performance. This pattern of results was also found by Cooper et al. (2015), who tested relational memory compared to item memory using a change-detection task, assessing recollection of item-specific and spatial details. Significantly fewer spatial changes were detected by the group with ASD, although they also detected significantly fewer item changes.

Several studies have also demonstrated evidence of intact relational memory, in the domain of implicit learning. This was tested by Nemeth et al. (2010) using an alternating serial reaction time task. During this task, an animal's head appeared on-screen in one of four locations, one at a time, and participants were required to press a key that corresponded to the location in which it appeared. Children with ASD were found to be unimpaired in their ability to learn the sequence, and also to remember it after a long delay (sixteen hours). Similar results were also demonstrated with adolescents and young adults with ASD during a

serial reaction time task, which tests implicit learning of a sequence (Travers, Klinger, Mussey, & Klinger, 2010). Intact performance was also found in several implicit learning tasks presented to children with ASD (Brown, Aczel, Jiménez, Kaufman, & Grant, 2010). Although some studies discussed here have found deficits in item memory rather than relational memory, it may be that these studies were carried out with more complex stimuli, which in turn taxed the overall cognitive abilities of these individuals. It can be argued therefore that most research points to the existence of a declarative relational memory deficit in ASD.

2.6. Relational memory and the hippocampus

Several lines of evidence converge to show that the medial temporal lobe, and more specifically the hippocampus, is an important brain region for the capacity for relational memory. The medial temporal lobe (MTL) comprises the hippocampal region, including the CA fields, dentate gyrus, and subicular complex, and the parahippocampal gyrus, which includes the perirhinal, entorhinal and parahippocampal cortices (Squire & Zola-Morgan, 1991). In humans, most neurogenesis in the MTL takes place prenatally (Alvarado & Bachevalier, 2000; Malik et al., 2013), although there are also postnatal changes that occur. The dentate gyrus continues to develop postnatally between the ages of four to six months old, and neurons in the hippocampus itself continue to change up to approximately ages five to six years old in humans. There is also a rapid increase in hippocampal volume over the first two years of life, which then slows, but continues to change up to age twelve (Utsunomiya, Takano, Okazaki, & Mitsudome, 1999).

The prenatal neurogenesis of the MTL would suggest that relational memory ability should be evident very early in life. However, although some aspects of memory do develop early in life (e.g. recognition memory), relational memory appears to develop later, at around

age two in monkeys and between ages five and seven in humans (Bachevalier & Vargha-Khadem, 2005), which corresponds with the progressive development of the hippocampus during the first years of life (Utsunomiya et al., 1999).

Eichenbaum (2000; 2001) argues that the hippocampus is important for encoding personal experiences into memory; specifically that it encodes objects, events, and the relations between them, and stores them as flexible representations, in order to allow for the adaptive recollection of the information. Likewise, O'Reilly and Rudy (2001) propose that the role of the hippocampus is to bind the elements of an event together into an overall unified representation which then allows later recall of the event even if only partial elements of the event are cued; a view which is also held by Montaldi and Mayes (2010), and Bird (2017).

A review of many years of research into recollection and familiarity found that recollection appears to rely on the connection between the hippocampus and prefrontal cortex (Yonelinas, 2002). Ghetti and Bunge (2012) also argue that episodic memory is acquired as a result of the development of a network between the prefrontal cortex, the posterior parietal cortex, and the hippocampus. Davachi (2006) postulates that the hippocampus is responsible for mediating information about the context in which an event takes place, whilst the perirhinal cortex is sufficient for memory for individual items. Brown and Aggleton (2001) propose that the hippocampus is responsible for judging whether a particular configuration of stimuli has previously been seen, and there is general agreement that the hippocampus is required for the ability to flexibly process the relations between items and events (Pascalis, Hunkin, Bachevalier, & Mayes, 2009; Opitz, 2010; Olsen, Moses, Riggs, & Ryan, 2012; Xue, 2018).

Neuroimaging evidence would appear to support this view, and lines of evidence are taken from several different tests of relational memory. Transitive inference tasks involve the flexible encoding of arbitrary relationships between pairs of stimuli, in order to infer relationships between other, previously unseen pairs. For example, if we learn that the relationship between A and B is that A is greater than B, and B is greater than C, we should be able to correctly infer that A is also greater than C, despite the fact that A and C have not been presented together. Preston, Shrager, Dudukovic, and Gabrieli (2004) presented this type of task to typical adults whilst they were scanned using fMRI, in which they were required to learn the relations between pairs of stimuli e.g. face (A) + house (B). They were then given another pair and required to learn the association between that pair e.g. house (B) + face (C), so that face A and face C were both associated with the same house. The anterior hippocampus was found to display greater activation during face–face pairs (which were transitively related via the same house), than for learned pairs (face-house). A similar pattern of results was found by Heckers, Zalesak, Weiss, Ditman, and Titone (2004) who presented participants with pairs of abstract shapes. This study found that the right anterior hippocampus in particular displayed greater activation during presentation of the transitive (non-overlapping) pairs (although see Acuna, 2002, who found greater activation in the prefrontal-parietal network during transitive inference).

Tasks of transverse patterning have also provided evidence of an association between activation in the hippocampus and relational memory. This task involves learning the relation between pairs of items, each element of which is reinforced and non-reinforced an equal number of times (e.g. A > B, B > C, C > A), and which requires an awareness of the flexible nature of the relations between the elements. A well-known example of this task is the "Rock-Paper-Scissors" game. Hopf et al. (2013) presented children and adults with a version of this task whilst scanning them using MEG, in which the individual stimuli were

abstract shapes. They found that a pattern of increased right hippocampal lateralisation led to better performance in transverse patterning. Tests of configural learning have also highlighted this association. Duncan, Doll, Daw, and Shohamy (2018) scanned participants using fMRI, while completing a test of configural learning in which they were required to predict which stimulus of a pair caused a certain outcome. This task could only be solved by having an awareness of the particular configuration of the stimuli. The authors found increased activity in the anterior hippocampus during this task.

Imaging studies carried out during oddity tasks also support the idea of a link between the hippocampus and relational memory. During one study with typical adults, participants were scanned using fMRI while being presented with four images. Three of these images were identical (but were shown from different angles), and one was different (the "oddity"). Performance on this task was found to be associated with increased hippocampal activation (Lee, Scahill, & Graham, 2007). It has also been demonstrated that greater activity in the hippocampus is predictive of successful relational memory. Hannula and Ranganath (2008) scanned participants using fMRI while presenting them with a three-dimensional grid displayed on-screen. During the study phase, four objects were placed in locations within the grid. During the test phase, the grid was displayed again containing four objects, the locations of which either matched that of the study phase or had been changed in some way to create a mismatch. Greater activation in the anterior and posterior hippocampus, as well as the perirhinal cortex, was found to lead to greater accuracy in the test phase. Findings such as these point to the conclusion that the hippocampus and adjacent structures of the MTL are important for the successful encoding and subsequent retrieval of relational information (Hannula & Ranganath, 2008; Monti, Cooke, Watson, Voss, Kramer, & Cohen, 2014).

The first indication of the lasting impact damage to the medial temporal lobe would have on memory came from research carried out in the 1950s. The publication of seminal research carried out with patient H.M. began to highlight the importance of these brain regions in memory processes. H.M. originally suffered from temporal lobe epilepsy, which caused seizures so severe that they could not be controlled with medication. This caused his physicians to take the drastic decision to resect his medial temporal lobe, which included the complete removal of the hippocampal formation. Although the surgery achieved some success in alleviating his seizures, it was immediately apparent that the loss of these brain regions had resulted in a profound effect on his memory ability. Although he displayed no deficits in other cognitive functions such as abstract thinking and reasoning ability, and his level of general intelligence did not significantly change (in fact his IQ appeared to slightly improve), severe deficits in his memory ability were demonstrated. His immediate recall, both of stories and drawings, was found to be significantly impaired, as was his ability to learn associations between pairs of words. This led to the conclusion that an intact hippocampus is a requirement for normal memory function (Scoville & Milner, 1957).

Subsequent research has focused on amnesia caused by damage to the MTL and has sought to provide further evidence of the importance of the hippocampus in memory. Much of this research has been carried out with non-human animals. Whilst this limits the extent to which findings of the effects of hippocampal damage on relational memory can be applicable to humans, they are useful in highlighting the effects of very localised damage, whereas studies of MTL damage in humans are not always focal enough to dissociate the functions governed by specific regions of the MTL.

Impairments in declarative memory have been subsequently found in humans with damage to the MTL. Vargha-Khadem et al. (1997) found delayed recall of stories, word lists,

and complex geometric figures to be impaired in children who had sustained early damage to the hippocampus, whereas their immediate recall was unimpaired, as were other cognitive functions such as the acquisition of language, factual knowledge, and literacy. A review of studies of developmental amnesia caused by hippocampal damage found these individuals to be impaired in episodic memory ability, whilst displaying intact semantic memory; they were also found to demonstrate intact recognition memory, whereas recollection was significantly impaired (Vargha-Khadem, Gadian, & Mishkin, 2001).

Episodic-like memory has also been tested in non-human animals with hippocampal damage. Mice were tested for their memory of objects they had previously explored, in addition to where and when they had explored them and were found to be impaired (DeVito & Eichenbaum, 2010). In studies of episodic memory and episodic future thinking carried out with humans, hippocampal damage is also shown to have a deleterious effect. During one study, participants were asked to produce narratives about past and potential future events. To test their episodic memory, they were given three minutes to produce a narrative about a personal past event (such as their graduation ceremony). To test episodic future thinking they were given the same length of time to imagine and produce a narrative about a potential event (such as winning the lottery). Alongside these tasks, they were also asked to produce narratives based on a detailed drawing they were shown. Participants were told to imagine the drawing was a scene from a film and were given three minutes to tell a story about that scene. Individuals with hippocampal damage were found to be impaired in both the episodic memory and future thinking tasks, but were found to be just as able to produce a narrative from a detailed drawing as the matched control group. The episodic memory and future thinking tasks also correlated positively with one another, further strengthening the idea of the important role the hippocampus plays in both (Race, Keane, & Verfaellie, 2011). This pattern of results was also found in a case study carried out with a patient with amnesia.

He was found to be significantly impaired in recalling past events, as well as producing information about probable future activities, whilst his semantic memory, tested by asking him to make judgements about whether a statement was factual or fictitious, was intact (Klein, Loftus, & Kihlstrom, 2002).

Studies of hippocampal lesions in monkeys appear to parallel those of individuals with developmental amnesia who also have pathology of the hippocampal formation. In a test of transverse patterning carried out with adult monkeys with hippocampal lesions, it was demonstrated that they were significantly impaired in learning the flexible relations between the stimuli. They were also given a delayed non-match to sample (DNMS) task. This task involved first a study phase, in which a rewarded stimulus in presented (the "sample"), after which several stimuli are presented, of which the rewarded stimulus is the one that does not match the previously presented sample. The monkeys were also found to be impaired at this task (Alvarado, Wright, & Bachevalier, 2002). Bachevalier and Mishkin (1994) also administered a DNMS task to monkeys with lesions of the MTL and found an impairment that increased steadily from the shortest delays.

Another study of transverse patterning was carried out with amnesic patients; this study also administered a non-configural test of visual discrimination, which could be solved by simple awareness of the elements, rather than the relations between them. Participants were found to be impaired only on the test of transverse patterning, indicating an impairment selective for relational memory (Rickard & Grafman, 1998). Reed and Squire (1999) found slightly different results in a transverse patterning task carried out with patients with damage to the hippocampal formation. Participants were also tested on a non-configural task, and the authors found that amnesic patients were impaired even when they were required to choose on the basis of the elements rather than the relations between those elements.

Despite the findings of an impairment in transverse patterning ability, success has also been demonstrated in this task in amnesia after hippocampal damage. Moses, Ostreicher, Rosenbaum, and Ryan (2008) found that, by providing semantically meaningful relationships between the stimuli – using playing cards, they exploited the previously known relationship between the Ace, King, and Two cards – they were able to elicit success in the task. In scanning participants using MEG while they carried out the task, it was found that the increased meaningfulness of these types of stimuli actually led to reduced activation in the hippocampus, and increased activation in the prefrontal and temporal cortices. This provides an explanation for intact transverse patterning performance in patients with hippocampal damage, as it indicates that they were more reliant on semantic information about the stimuli.

In addition to these findings, sensitivity to hippocampal damage has also found in studies of incidental relational memory. Tests of novelty preference have been utilised to investigate the awareness of the way presented stimuli are related to each other. One example of this kind of task is a change detection test. This task involves presenting participants with a scene, and after a short delay, that same scene is presented with visual changes made in the relations between elements of the scene. Amnesic participants were presented with an image of a real-word scene (such as a park), and after a short delay the same scene was presented with visual manipulations of the scene; this included the addition, deletion, or shifting of certain objects within the scene. Measurement of eye movements demonstrated that participants were sensitive to the change at short (Ryan & Cohen, 2004), but not longer, delays between the presentations (Ryan, Althoff, Whitlow, & Cohen, 2000), indicating that the hippocampus is involved in the long-term retention of relational information. Another type of task used to study novelty preference is the visual paired comparison (VPC) task, which investigates the awareness of how a pair of stimuli are related to each other. During this task, a single object is first presented (the study phase), and then

after a delay which can be variable, the same object is presented alongside a completely new object (the test phase). If the participant is aware of which stimulus was previously presented, they will look significantly longer to the new stimulus, thereby displaying a novelty preference. This task assesses the incidental encoding and retrieval of the arbitrary associations between items and the context in which they are presented. This task was carried out with rhesus macaques who were given lesions of the hippocampus and tested on a VPC, using different lengths of delay between the study and test phases. The macaques with lesions were found to display significantly less of a novelty preference than animals that were not given lesions (Zeamer, Heuer, & Bachevalier, 2010). Likewise, adult monkeys given hippocampal lesions also showed no novelty preference when delays between the study and test phase were longer than thirty seconds. This study also found that the hippocampally-damaged animals displayed a novelty preference during a DNMS task, leading the authors to conclude that success on DNMS tasks was not dependent on the hippocampus and that VPC ability was more sensitive to damage to the hippocampus (Pascalis & Bachevalier, 1999). This pattern of results was also found in a study of gaze behaviour by Nemanic, Alvarado, and Bachevalier (2004), who tested adult monkeys on a VPC task with different lengths of delay, and also a DNMS task. Monkeys with hippocampal lesions were found to be impaired on the VPC task at short delays (i.e. sixty seconds), whereas they did not display impairments on the DNMS task until long delays (i.e. six hundred seconds). The authors concluded that recollection is necessary for success in a VPC task, whereas familiarity is sufficient in DNMS tasks.

However, rhesus monkeys with hippocampal damage have been found to be impaired in a test of DNMS, as well as in transverse patterning ability (Alvarado et al., 2002). Likewise, Zola et al. (2000) also found monkeys with hippocampal lesions to be impaired on both DNMS and VPC tasks. An explanation of this may be that these were tasks in which

animals had to make a choice, therefore this was testing intentional rather than incidental encoding. Intentional encoding may be more effortful and therefore more sensitive to damage.

For a number of years it has been theorised that ASD-related difficulties with memory are due in part to dysfunction of the medial temporal lobe (Damasio & Maurer, 1978; DeLong, 1992). Although no precise parallel has been demonstrated between ASD and MTL amnesia, several lines of evidence exist to support the view of the hippocampus' involvement in relational memory. Loveland, Bachevalier, Pearson, and Lane (2008) administered tasks which are generally accepted to measure the function of the MTL, and in particular the hippocampus: the spatial memory span and spatial delayed alternation tasks. During the spatial memory span task, a reward was placed in one of several locations on a grid in front of the participant. After the participant found the reward, another reward was placed in a new location on the grid. This procedure was followed several times, each time with the reward being placed in a new location. The participant was required to remember in which of the locations the reward was previously placed, in order to choose the correct (i.e. new) location. During the spatial delated alternation task, a tray with three wells was placed in front of the participant, with the two outside wells covered; a reward was placed in one of the covered wells. Subsequent trials placed the reward in the well on the alternate side from that which contained it before (i.e. left-right-left and so on). The participant had to remember in which location the reward had previously been found to be able to choose the alternate location on the next trial. Children with ASD displayed impaired performance on both of these tasks compared to matched controls, whereas they were found to have intact item-specific memory. Likewise, findings already detailed in this chapter demonstrate diminished recognition of item-location and item-colour combinations in higher-functioning adults with ASD, in the presence of intact recognition of each separate component (Bowler et al., 2014).

Findings such as these mirror those from individuals with amnesia caused by damage to the MTL, and in particular the hippocampus. Adults with hippocampal damage were tested on their memory for objects, their locations, or conjunctions of object + location. Their recognition of the separate entities was intact, whilst their recognition of the conjunctions was significantly impaired (Olson, Page, Moore, Chatterjee, & Verfaellie, 2006). This pattern of results was also found by Holdstock et al. (2002a), who found an adult with hippocampal damage to be impaired in the recognition of the association between an object and the location in which it was presented. The same patient was also found to be impaired in the free recall of items, and learning of new semantic information, whereas their recognition of items was intact (Holdstock et al., 2002b; Mayes, Holdstock, Isaac, Hunkin, & Roberts, 2002).

Several imaging studies also lend support to the theory of a parallel in memory difficulties between ASD and hippocampal dysfunction. Adults with ASD, matched on IQ with typical adults, were asked to study word triplets while in a fMRI scanner. They were found to be impaired in the recollection of the word triplets, whilst their familiarity-based retrieval was intact. A link was also found between relational encoding and recollection for both groups, and there was a marginal decrease in hippocampal activation for the group with ASD (Gaigg et al., 2015). Cooper et al. (2017) presented participants with a test of recall for features of objects while scanning them using fMRI. Adults with ASD were found to be significantly impaired in this task compared to matched controls, and were also found to have significantly reduced connectivity between the hippocampus and the fronto-parietal network.

Similarities have also been found in studies using structural imaging of the MTL in ASD. Children with ASD, matched with controls on age and IQ, completed several memory tasks, testing both episodic and semantic memory, and were then scanned using structural

MRI. The episodic memory tasks included tests of "everyday" memory, such as memory for the names of people presented to them in photographs, memory for their own belongings, and memory for personal appointments, as well as recall of stories. They were found to be impaired in the episodic tasks, whilst having intact semantic memory. Investigation of the structure of the MTL in these participants also revealed bilateral abnormalities in the hippocampal formation, as well as a positive correlation between parental ratings of ASD symptoms and the grey matter of the amygdala, hippocampus, and entorhinal cortex (Salmond et al., 2005).

Bilateral abnormalities were also found in the MRI scans of infants who later developed impairments in cognitive abilities such as language, social skills and adaptive behaviours, impairments which are closely associated with the cognitive profile of ASD (DeLong & Heinz, 1997). In adults and children with ASD, structural abnormalities have been found in the hippocampus (Bauman & Kemper, 1985; Raymond, Bauman, & Kemper, 1995). Although data from imaging studies (e.g. Piven, Bailey, Ranson, & Arndt, 1998) has not been consistent, other studies show subtle regional reductions in hippocampal size in children with ASD, in the absence of any ASD-related structural differences in the hippocampus (Nicolson et al., 2006).

Autism has previously been called a "developmental syndrome of hippocampal dysfunction" (DeLong, 1992), and whilst it may not be as simple as this in terms of hippocampal dysfunction causing the characteristics of ASD other than memory patterning (Ben-Shalom, 2003), the findings detailed above would appear to point to a possible dysfunction in the hippocampus in ASD, which would be a potential candidate for the cause of the deficits seen in relational memory in this population.

2.7. Aims of the current research

It is suggested that episodic memory is impaired across the autism spectrum (Boucher & Anns, 2018); however, evidence from memory studies demonstrating impaired relational processing has most commonly been based on the learning of verbal material (such as lists of words) by verbally-able participants with ASD, who are matched to a control group on full-scale IQ scores. This limits any commentary on the universality of these difficulties across the spectrum. Higher-functioning individuals may process verbal material in idiosyncratic ways, therefore existing tasks may simply measure this, rather than difficulties related specifically to memory. The current research therefore aimed to develop a set of non-verbal tasks that test relational memory, to examine the level of this ability in lower-functioning children with autism. It aimed to replicate some of the characteristic impairments found in relational memory in high-functioning individuals on the autism spectrum, to attempt to generalise these impairments to the autism spectrum as a whole.

The research proposed to achieve its objectives by developing behavioural paradigms which have already been used with non-human animals, and which measure relational memory non-verbally, adapting them for use with humans with and without ASD. This would provide paradigms suitable for use with all participants with ASD, regardless of the level of verbal ability, and would provide a more rigorous test of relational memory in ASD, independent of the level of functioning of the individual.

Chapter 3: Study 1: Structural learning in Autism Spectrum Disorder

3.1. Introduction

The characteristic memory patterning in ASD points to a difficulty with relational memory. However, previous research has tended to focus on participants who are verbally-able, using stimuli that is verbalisable. The current study aimed to measure relational memory non-verbally in ASD, using a paradigm adapted from the animal literature on relational memory, in order to answer the question of whether the relational memory profile of less verbally-able individuals with ASD is comparable to that of individuals with ASD who have no language impairments.

3.2. Structural discrimination

The ability to encode and store in memory the structure and configuration of stimuli has been identified as being dependent on hippocampal function (Sutherland & Rudy, 1989). Support for this idea was found by Rudy and Sutherland (1989), who presented rats with a task in which success was dependent upon the awareness of a particular combination of elements of a compound stimulus. Reinforcement was given if the rats pressed a bar when either a light or a tone was presented; however, if the two stimuli were presented together, they were not reinforced. To solve this task, awareness of the distinction between the compound stimuli and the individual components was required. Rats who had hippocampal damage were significantly impaired at this task, although they were able to solve a simple task in which they had to discriminate between a light and a tone.

Although this pointed to the hippocampus as being important for learning stimuli configuration, subsequent studies found no impairment in this kind of task (e.g. Davidson, McKernan, & Jarrard 1993). This led to a refinement of the theory to posit that the

hippocampus processes the configuration and spatial arrangement of visual arrays (Aggleton & Pearce, 2001). Tasks that measure this ability can be defined as tests of structural discrimination, which are a subset of configural learning. In tests of configural learning, participants need only be aware of what particular elements are present in a compound stimulus; in a structural learning task however, there must also be an awareness of the spatial arrangement of those elements.

The idea of the hippocampus' importance in this kind of task was tested by Sanderson, Pearce, Kyd, and Aggleton (2006), who administered various configural tasks to rats, one of which was a structural discrimination task. The animals were trained on these tasks before receiving hippocampal lesions, after which they were trained again on the same tasks. It was found that while they were not impaired at re-learning two other configural tasks, a biconditional discrimination task, and a transverse patterning task, they were significantly impaired in re-learning the structural discrimination task. In addition to this, Aggleton, Sanderson, and Pearce (2007) found that hippocampectomised rats were impaired on a configural learning task only when the spatial arrangement of the stimuli was important. Rats were presented with a pair of compound stimuli, which were mirror images of each other. Both stimuli included the same elements (e.g. black and white) but were presented in a different spatial configuration (e.g. black on the left of white, paired with white on the left of black). This meant that the animals had to demonstrate an awareness of the spatial arrangement of the individual elements, in order to correctly choose the reinforced stimulus (e.g. a stimulus comprising black and white was only reinforced if black was on the left of white). As each stimulus comprised the same elements, rats had to remember the specific spatial arrangement of each one to be able to choose the reinforced one.

As the hippocampus has been implicated in the difficulties with relational memory seen in ASD, and structural discrimination tasks have been shown to measure hippocampal

function in non-human animals, the current study aimed to adapt two of these tasks for use with human participants, in order to test the relational memory of individuals with ASD at all levels of functioning.

3.3. Study 1: Experiments 1 and 2

This study adapted a structural discrimination paradigm from the non-human relational memory literature (Sanderson et al., 2006; Aggleton et al., 2007). This consisted of two visual discrimination tasks using pairs of black and white stimuli displayed on a touchscreen laptop computer, and which required minimal verbal instructions for the participants. Participants were required to discriminate between two compound stimuli, which each comprised simple elements, such as black, white, stripes, and black with a white oval. Two stimuli were presented on-screen side by side, and participants were required to find the correct stimulus. Participants chose between the pair by touching the stimulus on the screen and were required to learn that touching each stimulus on-screen would result in a different outcome. The study consisted of two configural discrimination tasks. In the biconditional discrimination task, two stimuli were presented, each including one identical element and one different. Participants were trained on pairs of stimuli, and were then presented with a test block, in which mirror images of previously learned compound stimuli were presented. This meant that an awareness of the configuration of the stimuli was necessary in order to succeed. The authors reasoned that the use of mirror images may actually impair performance in participants sensitive to the spatial arrangement, whereas participants who are simply aware of the configuration would display no impairment. The structural discrimination task also contained identical elements, but each stimulus contained a different spatial arrangement of those elements, meaning that success was dependent upon the awareness of the spatial arrangement of each stimulus (Fig. 3.1).

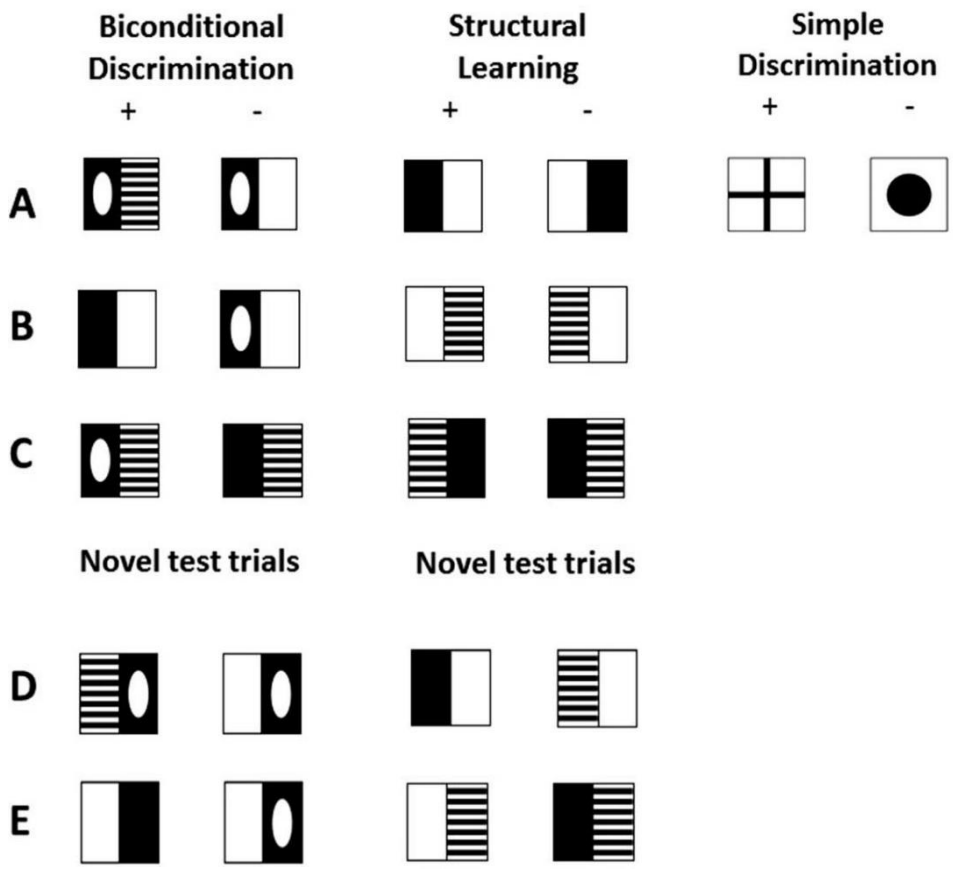

Figure 3.1. Examples of test stimuli. Biconditional discrimination with test trials presenting mirror images (Rows D and E); Structural discrimination/learning with test trials presenting re-paired stimuli (Rows D and E); Simple discrimination task; randomly interspersed throughout biconditional and structural discrimination tasks. "+" indicated reinforced stimulus. Adapted from Sanderson et al. (2006).

A simple discrimination task was included as part of each experimental task; this involves no configural or spatial component and was included to determine that participants were able to selectively discriminate between very simple stimuli.

The ages of participants ranged from seven to eleven for the typically-developing participants. This age range was chosen due to previous research that shows that although some forms of relational memory can be demonstrated in very young typically-developing children (e.g. Newcombe, Huttenlocher, Drummey, & Wiley, 1998; Richmond & Nelson, 2009), other research points to this ability becoming adult-like at around age six (e.g. Sluzenski, Newcombe and Kovacs. 2006; Overman, Bachevalier, Miller, & Moore, 1996;

Rudy, Keith, & Georgen,1993). Typically-developing participants were matched on non-verbal ability with participants with ASD and reduced language.

The characteristic impairments already demonstrated in the relational binding abilities of individuals with ASD led to the prediction that they would, regardless of developmental level, perform significantly more poorly than typical individuals in a test of structural discrimination, whereas their performance in another test of configural discrimination would be unimpaired.

3.4. Experiment 1: Biconditional discrimination

3.5. Method

3.5.1. Participants

A total of twenty-five school-aged children were recruited, comprising two groups. Thirteen children (ten males and three females) aged between eleven and sixteen with an autism spectrum disorder were recruited from four special educational secondary schools in the London area. All participants in this group had a confirmed diagnosis of an autism spectrum disorder, according to school records of each child's statement of special needs. Where possible, this diagnosis was supported by scores obtained from completion by teachers of the Social Responsiveness Scale (SRS, Constantino, 2005). Participants in this group also had reduced language, which was confirmed by scores obtained from completion by the researcher of the British Picture Vocabulary Scale: Third Edition (BPVS-III, Dunn, Dunn, & Styles, 2009).

To form the comparison group, twelve children (six boys and six girls) aged between seven and eleven were recruited from two mainstream primary schools, also in the London

area. As reported by the schools, none of these children had any developmental or learning difficulties, which was confirmed by completion by teachers of the SRS. They displayed verbal ability within the typical range for their age; this was confirmed by completion by the researcher of the BPVS-III for each child.

The study was approved by the City, University of London Ethics committee, and informed consent was obtained first from the headteacher of each participating school (Appendices 1 & 2), and then from each child's parent or carer (Appendix 3). Verbal assent was also obtained from each child before each testing session began.

Typically-developing participants (TD group) were matched on non-verbal ability to participants with an autism spectrum disorder (ASD group), to within two points on Raven's Coloured Progressive Matrices (RCPM, Raven, 1976). Independent t-tests were carried out using age and psychometric data from each group and found no significant difference between the groups on non-verbal ability. Significant differences were found between the groups on age, symptoms of autism spectrum disorder, and verbal ability (see Table 3.1.).

Table 3.1. Participant characteristics: Experiment 1 (Means and Standard Deviations)

	TD (n = 12)	ASD (n = 13)	t	p	Cohen's d
Age (months)	103.9(13.96)	160.98(15.67)	-9.59	< .001	3.85
Range	88-124	136-191			
SRS	20.17(16.65)	81.80(19.12)	-8.09	< .001	3.44
Range	1-62	47-105			
NVA	28.5(4.93)	26.77(5.42)	0.83	.413	0.33
Range	19-34	18-34			
Percentile	50.39(29.53)	21.02(28.46)			
VA	105.17(16.99)	83.77(32.6)	2.08	.054	0.82
Range	91-139	41-144			
Percentile	30.1(25.29)	5.15(10.53)			

Note. SRS = Social Responsiveness Scale (raw score), cutoff = 70; NVA = Non-verbal ability (Raven's Coloured Progressive Matrices, raw score); VA = Verbal ability (British Picture Vocabulary Scale-III, raw score).

3.5.2. Materials and Design

Stimuli were created by putting together shapes in Microsoft PowerPoint, to create each compound stimulus. Each stimulus was black and white, and measured 10cm x 10cm. Each compound stimulus' left and right halves were distinct from each other in some respect (Fig. 3.1). The individual stimuli were presented as a pair on a white screen, using E-Prime software on a 15" Dell touchscreen laptop computer. Each stimulus was either positively or negatively reinforced. If the "correct" stimulus was chosen, positive feedback was given on screen; specifically a "smiley face" was displayed. If the "incorrect" stimulus was chosen however, negative feedback was displayed; this took the form of a "frowny face" (Fig 3.2).

A practice phase was given initially; this was a test of simple discrimination, in which participants learned that touching one of the stimuli would result in a specific outcome. This was administered to confirm that the instructions had been understood by the participant, and in the case of less verbally-able participants, also served to physically model the required behaviour for them so that they could simply copy the experimenter, rather than having to process verbal instructions. After the practice phase was successfully completed, the

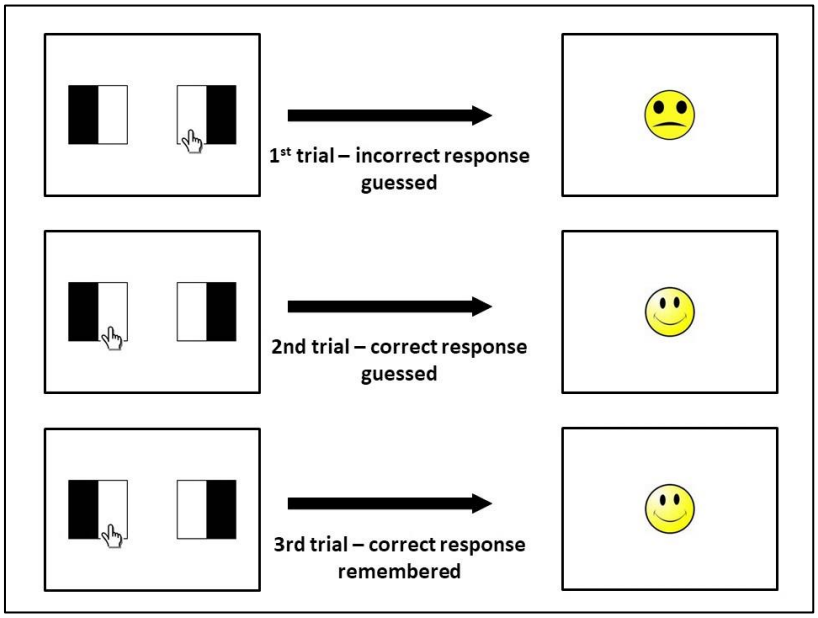

Figure 3.2. Example of practice trials and on-screen feedback

biconditional discrimination task was administered. This task consisted of a total of five blocks: four training blocks and one test block.

During the training blocks, the experimental stimuli were successively introduced until all stimuli were presented in random order in the final training block. The test block followed directly after the four training blocks. The simple discrimination task was interspersed throughout the training and test blocks; this was done to ensure that participants were maintaining proper attention to the task, were not pressing stimuli randomly, and that they were able to discriminate between basic stimuli without a configural or structural component (Fig 3.1).

Participants' responses were collected via the touchscreen facility on the laptop. Accuracy, reaction times for correct trials, and number of attempts during the training phase were measured. Data were analysed using SPSS 23.0. For the training phase, a 2 x 4 mixed repeated measures design was used, with a repeated measures variable of Training Block (1–4). The between-participants variable was Group (TD x ASD). For the test phase, a 2 x 2 mixed repeated measures design was used, with a repeated measures variable of Trial Type (Familiar x Novel). The between-participants variable was Group (TD x ASD).

3.5.3. Procedure

Participants were tested individually, as part of the normal school day, in a quiet room away from their usual classroom. Participants sat in front of the computer screen and they were asked to confirm whether they were happy to begin the task. Participants were provided with simple verbal instructions about the task: "You'll see two pictures together; touching one of them will show a smiley face and touching the other one will show a sad face, and you need to find the smiley".

On the first practice trial, the experimenter showed the participant how to register a choice of stimulus on the screen, by touching one of the images on the screen itself. During the first practice trial, the experimenter purposefully touched the "incorrect" stimulus on the screen, and the negative feedback (i.e. the "frowny" face) appeared on the screen. The next practice trial was then displayed; this time the experimenter purposefully chose the "correct" stimulus of the pair. This procedure was carried out in order to observe that the participant fully understood the difference between the positively and negatively reinforced stimuli. On the third practice trial, the participant was encouraged to make the choice themselves. If the participant correctly chose the positively reinforced stimulus, they were then encouraged to "find as many smileys as you can". If the participant did not fully understand the contingencies of the task, the testing session was terminated at this stage. This occurred with one participant from the ASD group and no participants from the TD group.

When it had been confirmed that the participant was happy to continue, the main experiment began. Each trial began with a blank screen which lasted for 1 second, after which a pair of stimuli appeared on-screen. These remained on-screen until the participant had made their choice. The feedback screen was then presented for 1.5 seconds, after which the next trial began. The first training block consisted of 12 trials in total. One pair of configural stimuli (e.g. BW+ BH-) was presented for 10 trials, and one pair of simple stimuli (S+ S-) was presented for 2 trials. The trials were presented in random order, with the left/right position of the stimuli counterbalanced so that the positively reinforced stimulus appeared on the left side and the right side an equal number of times. The second training block consisted of 14 trials. Here, a new pair of configural stimuli was introduced (e.g. OH+ OW-); this pair was presented for 10 trials. The previous experimental pair (BW+ BH-) was presented for 2 trials, and the simple discrimination task was presented for 2 trials. Trials were again presented in random order. The third training block consisted of 26 trials. Here,

two new pairings of configural stimuli were introduced, which were re-pairings of stimuli previously seen (e.g. BW+ OW-; OH+ BH). The new pairings were presented for 10 trials each. The previously seen pairings (e.g. BW+ BH-; OH+ OW-) were presented for 2 trials each, and the simple discrimination was presented for 2 trials. Trials were again presented in random order. The fourth and final training block consisted of 18 trials. Each pair of configural stimuli was presented for 4 trials, and the simple discrimination was presented for 2 trials. Trials were again presented in random order. Examples of trial presentation and reinforcement protocols are displayed in Table 3.2.

Performance criteria for the first three training blocks were set at 80% for experimental trials, and 50% for simple discrimination trials. For the fourth training block the criteria were set at 75% for experiment trials, and 50% for simple discrimination trials. If these criteria were attained on the first attempt, the task moved automatically on to the next block. If these criteria were not attained, the same training block was presented again. The experiment allowed participants to attempt each training block a maximum of three times before it continued automatically to the next block.

After the training phase was completed, the test phase began directly after it, which consisted of a total of 36 trials. During this block, each pair of stimuli that had been previously seen ("Familiar") was presented for 4 trials each. Participants were also presented with previously unseen pairs of stimuli ("Novel"). These stimuli were mirror images of the previously seen stimuli from the training phase (e.g. WB+ WO-; HO+ HB-), creating four new pairs of stimuli, which were presented for 4 trials each. The simple discrimination task was presented for 4 trials. The test block was presented once, with no criterion set. Examples of trial presentation and positive/negative reinforcement protocols are displayed in

Table 3.3. On-screen feedback during the test phase was given in the same way as the training phase. Participants were also given verbal encouragement throughout the task.

Table 3.2. Presentation of trials during training phase: Experiment 1

Training block							
1		2		3		4	
Pair	Trials	Pair	Trials	Pair	Trials	Pairs	Trials
BW+BH-	x10	OH+OW-	x10	BW+OW-	x10	BW+OW-	x4
S+ S-	x2	BW+BH-	x2	OH+ BH-	x10	OH+ BH-	x4
		S+ S-	x2	OH+OW-	x2	OH+OW-	x4
				BW+BH-	x2	BW+BH-	x4
				S+ S-	x2	S+ S-	x2

Note. Pair = Stimuli pair presented together; Trials = Number of trials per training block; "+" = Positively reinforced stimulus; "-" = Negatively reinforced stimulus.

Table 3.3. Presentation of trials during test phase: Experiment 1

Familiar		Novel	
Pair	Trials	Pair	Trials
BW+ OW-	x4	WB+ HB-	x4
OH+ BH-	x4	WB+ WO-	x4
OH+ OW-	x4	HO+ HB-	x4
BW+ BH-	x4	HO+ WO-	x4
S+ S-	x4		

Note. Pair = Stimuli pair presented together; Trials = Number of trials per block; "+" = Positively reinforced stimulus; "-" = Negatively reinforced stimulus.

3.6. Results

3.6.1. Simple discrimination task

3.6.1.1. Accuracy

Mean accuracy scores for the simple discrimination task were compared across the four training blocks and the test block; the data are displayed in Table 3.4. A 2 (Group) x 5 (Block) mixed repeated measures ANOVA was used. Mauchly's test indicated that the

assumption of sphericity had been violated ($X^2(9) = 47.18$, $p < .001$), therefore degrees of freedom were corrected using Greenhouse-Geisser estimates of sphericity ($\varepsilon = .59$). No significant interaction was found between Block x Group: $F(2.37, 54.53) = 1.59$, $p = .209$, $\eta_p^2 = .07$. There was also no significant main effect of Group: $F(1, 23) = 1.13$, $p = .300$, $\eta_p^2 = .05$. However, the main effect of Block was found to be significant: $F(2.37, 54.53) = 14.86$, $p < .001$, $\eta_p^2 = .39$.

Table 3.4. Accuracy scores for simple discrimination task: Experiment 1 (Means and Standard Deviations)

Block	TD (n = 12)	ASD (n=13)	Cohen's d
1	.63 (.23)	.70 (.26)	0.29
2	.84 (.22)	.79 (.34)	0.17
3	1.00 (.00)	.86 (.19)	1.04
4	1.00 (.00)	.88 (.22)	0.77
Test	1.00 (.00)	.94 (.15)	0.57

Note. TD = Typically developing; ASD = Autism spectrum disorder.

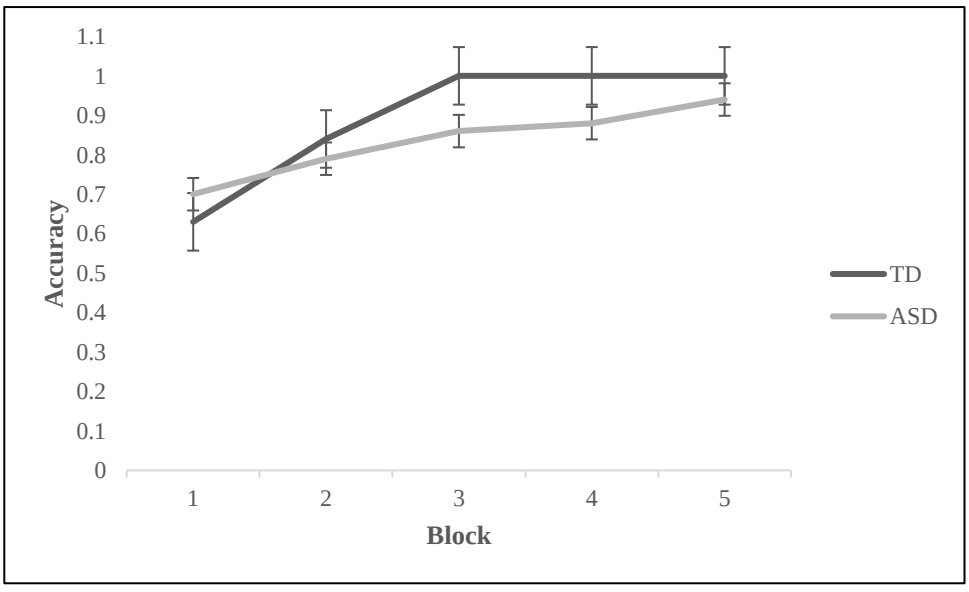

Figure 3.3. Accuracy ($M \pm$ SEM) for simple discrimination trials of Experiment 1. TD = Typically developing; ASD = Autism spectrum disorder.
Blocks 1-4 = Training phase; Block 5 = Test phase.

3.6.1.2. Accuracy compared to chance

Additional tests were carried out to determine whether the performance for the simple discrimination task was significantly above chance for both groups across the blocks. A one-sample t-test was used, with the chance level set at 0.5. Participants in the TD group performed significantly above chance in all but the first training block (Block 1: $t(11) = 1.92$, $p = .082$, $d = 0.55$; Block 2: $t(11) = 5.35$, $p < .001$, $d = 1.54$), and performed at ceiling for the final two training blocks and the test block. Participants in the ASD group performed significantly above chance across all the blocks (Block 1: $t(12) = 2.72$, $p = .019$, $d = .75$; Block 2: $t(12) = 3.11$, $p = .009$, $d = .86$; Block 3: $t(12) = 6.79$, $p < .001$, $d = 1.88$; Block 4: $t(12) = 6.29$, $p < .001$, $d = 1.74$; Test Block: $t(12) = 10.65$, $p < .001$, $d = 2.95$).

3.6.1.3. Reaction time

Mean reaction times for the correct trials of the simple discrimination which was interspersed throughout the biconditional discrimination task were compared across the four training blocks and the test block; the data are displayed in Table 3.5. A 2 (Group) x 5 (Block) mixed repeated measures ANOVA was used. Mauchly's test indicated that the assumption of sphericity had been violated ($X^2(9) = 21.49$, $p = .011$), therefore degrees of freedom were corrected using Greenhouse-Geisser estimates of sphericity ($\varepsilon = .80$). No significant interaction was found between Block x Group: $F(3.21, 73.93) = 1.38$, $p = .255$, $\eta_p^2 = .06$. There was also no significant main effect of Group: $F(1, 23) = 1.56$, $p = .224$, $\eta_p^2 = .06$. However, the main effect of Block was found to be significant: $F(3.21, 73.93) = 5.27$, $p = .002$, $\eta_p^2 = .19$.

Table 3.5. Reaction times for correct trials of simple discrimination task: Experiment 1 (Means and Standard Deviations)

Block	TD (*n* = 12)	ASD (*n*=13)	Cohen's *d*
1	3012.83 (1415.0)	2236.58 (965.35)	0.64
2	2731.36 (1504.64)	1970.5 (999.46)	0.60
3	1632.38 (477.08)	1905.99 (1438.4)	0.26
4	1690.3 (761.29)	1502.9 (672.33)	0.26
Test	2026.73 (1301.06)	1727.51 (838.13)	0.27

Note. TD = Typically developing; ASD = Autism spectrum disorder; Reaction time (ms).

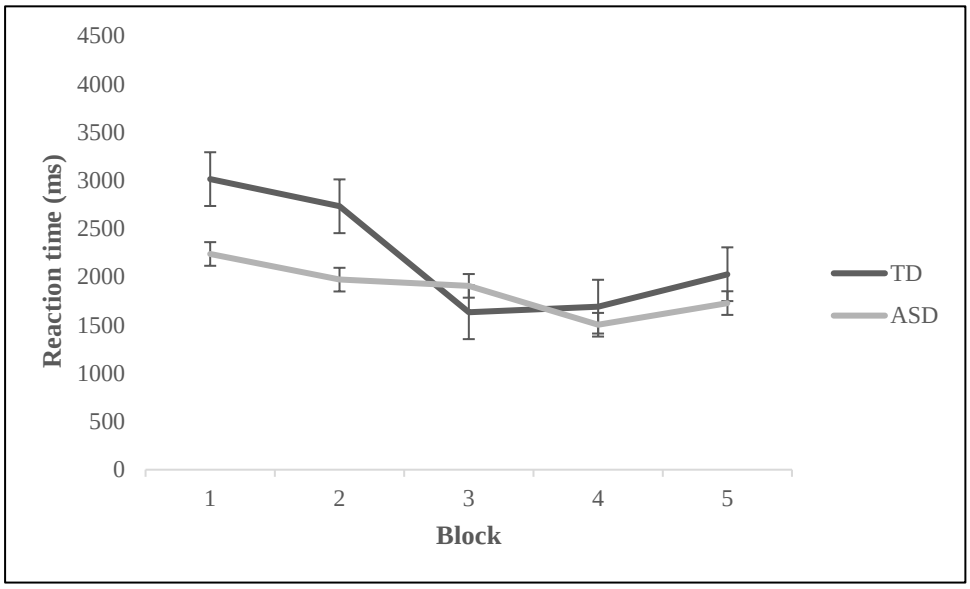

Figure 3.4. Reaction times (*M* ± SEM) for correct trials of simple discrimination task: Experiment 1. TD = Typically developing; ASD = Autism spectrum disorder.

3.6.2. Training phase

3.6.2.1. Accuracy

Mean accuracy scores for the biconditional discrimination task were compared across the four training blocks. The data are displayed in Table 3.6. A 2 (Group) x 4 (Block) mixed repeated measures ANOVA was used. Mauchly's test indicated that the assumption of sphericity had been violated ($X^2(5) = 22.49$, $p < .001$), therefore degrees of freedom were corrected using Greenhouse-Geisser estimates of sphericity ($\varepsilon = .59$). No significant

interaction was found between Block x Group: $F(1.76, 40.54) = 2.90$, $p = .073$, $\eta_p^2 = .11$. However, there was a significant main effect of Group: $F(1, 23) = 12.16$, $p = .002$, $\eta_p^2 = .35$. There was also a significant main effect of Block: $F(1.76, 40.64) = 10.80$, $p = .003$, $\eta_p^2 = .32$.

Table 3.6. Accuracy scores for training phase: Experiment 1 (Means and Standard Deviations)

Block	TD (*n* = 12)	ASD (*n* = 13)	Cohen's *d*
1	.94 (.06)	.88 (.10)	0.73
2	.89 (.06)	.80 (.11)	1.02
3	.85 (.08)	.79 (.19)	0.41
4	.89 (.11)	.67 (.23)	1.22

Note. TD = Typically developing; ASD = Autism spectrum disorder.

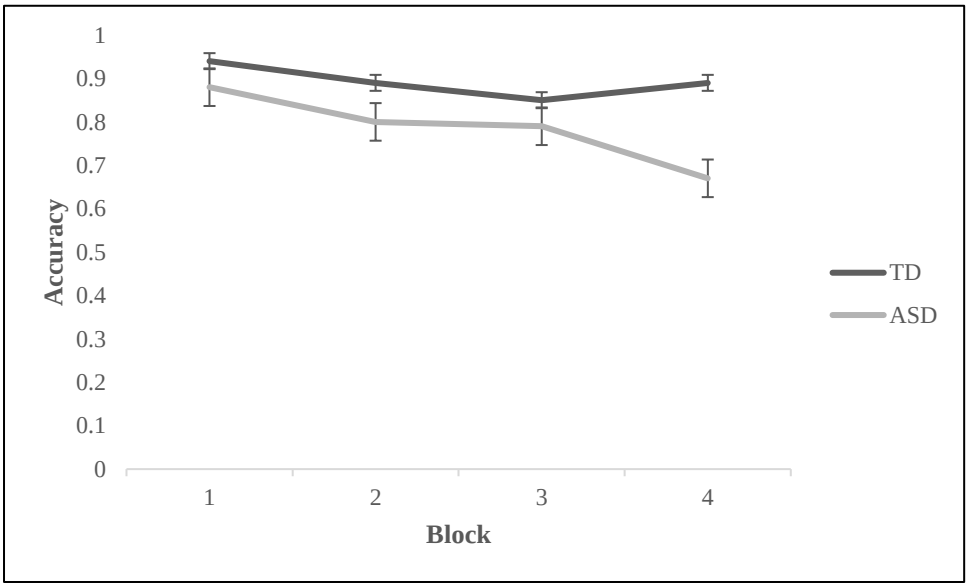

Figure 3.5. Accuracy (*M* ± SEM) for training phase of Experiment 1. TD = Typically developing; ASD = Autism spectrum disorder.

3.6.2.2. Accuracy compared to chance

Additional tests were carried out to determine whether the performance for biconditional discrimination training was significantly above chance for both groups across the blocks. A one-sample t-test was carried out, with the chance level set at 0.5. Participants in the TD group performed significantly above chance in all training blocks (Block 1: $t(11) =$

23.53, $p < .001$, $d = 6.79$; Block 2: $t(11) = 21.33$, $p < .001$, $d = 6.16$; Block 3: $t(11) = 14.69$, $p < .001$, $d = 4.24$; Block 4: $t(11) = 11.81$, $p < .001$, $d = 4.41$). Participants in the ASD group also performed significantly above chance across all the blocks (Block 1: $t(12) = 14.39$, $p < .001$, $d = 3.99$; Block 2: $t(12) = 9.40$, $p < .001$, $d = 2.61$; Block 3: $t(12) = 3.20$, $p = .008$, $d = 0.89$; Block 4: $t(12) = 2.69$, $p = .020$, $d = 0.75$).

3.6.2.3. Reaction time

Mean reaction times for correct trials of the biconditional discrimination task were compared across the four training blocks; the data are displayed in Table 3.7. A 2 (Group) x 4 (Block) mixed repeated measures ANOVA was used. No significant interaction was found between Block x Group: $F(3, 69) = 0.49$, $p = .694$, $\eta_p^2 = .02$. There was also no significant main effect of Group: $F(3, 69) = 0.95$, $p = .341$, $\eta_p^2 = .04$. However, the main effect of Block was found to be significant: $F(3, 69) = 4.02$, $p = .017$, $\eta_p^2 = .15$.

Table 3.7. Reaction times for correct trials of training phase: Experiment 1 (Means and Standard Deviations)

Block	TD (n = 12)	ASD (n = 13)	Cohen's d
1	1691.28 (413.52)	1718.47 (507.94)	0.06
2	2288.76 (1150.08)	1873.26 (834.08)	0.41
3	2669.7 (1244.91)	2355.68 (1660.32)	0.21
4	2728.59 (1180.85)	2145.37 (1535.77)	0.43

Note. TD = Typically developing; ASD = Autism spectrum disorder. Reaction time (ms).

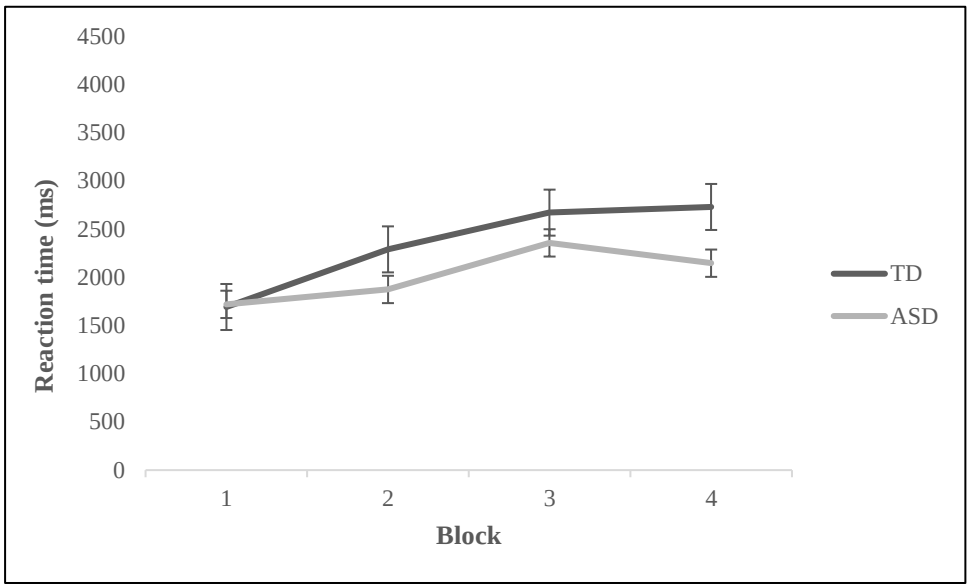

Figure 3.6. Reaction times (*M* ± SEM) for correct trials of training phase of Experiment 1. TD = Typically developing; ASD = Autism spectrum disorder.

3.6.2.4. Number of attempts

The mean number of attempts for the biconditional discrimination task were compared across the four training blocks. The data are displayed in Table 3.8. A 2 (Group) x 4 (Block) mixed repeated measures ANOVA was used. Mauchly's test indicated that the assumption of sphericity had been violated ($X^2(5) = 12.13$, $p = .033$), therefore degrees of freedom were corrected using Greenhouse-Geisser estimates of sphericity ($\varepsilon = .72$). No significant interaction was found between Block x Group: $F(2.15, 49.39) = 0.72$, $p = .502$, $\eta_p^2 = .03$, and there was no main effect of Group: $F(1, 23) = 3.63$, $p = .069$, $\eta_p^2 = .14$. However, there was a significant main effect of Block: $F(2.15, 49.39) = 10.56$, $p < .001$, $\eta_p^2 = .32$.

Table 3.8. Number of attempts per training block: Experiment 1 (Means and Standard Deviations)

Block	TD (n = 12)	ASD (n = 13)	Cohen's d
1	1.08 (0.29)	1.31 (0.63)	0.47
2	1.42 (0.70)	1.69 (0.75)	0.37
3	1.75 (0.87)	2.31 (0.95)	0.61
4	1.67 (0.78)	2.31 (0.95)	0.74

Note. TD = Typically developing; ASD = Autism spectrum disorder.

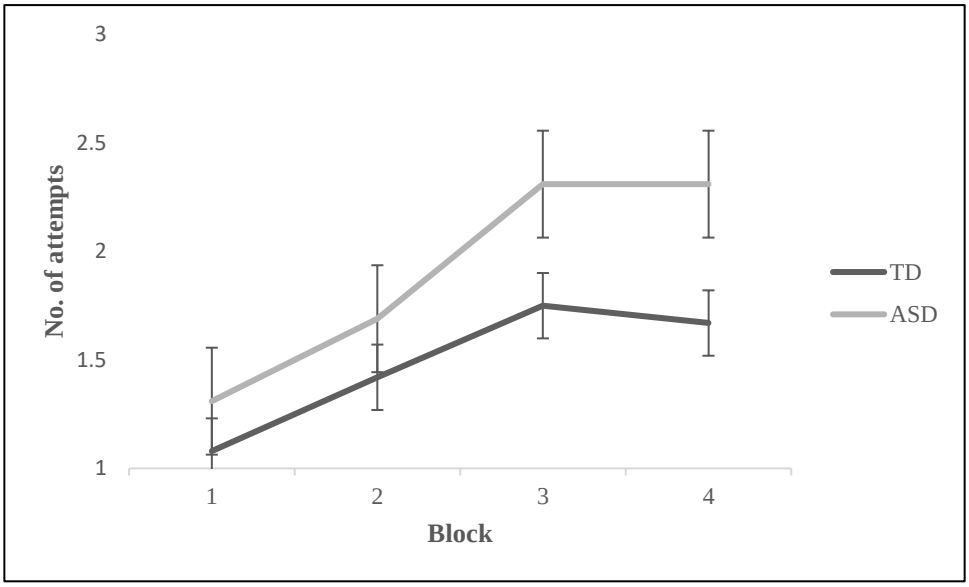

Figure 3.7. Number of attempts (M ± SEM) for each training block of Experiment 1. TD = Typically developing; ASD = Autism spectrum disorder.

3.6.3. Test phase

3.6.3.1. Accuracy

The mean accuracy scores of the two trial types (Familiar x Novel) during the test phase of the biconditional discrimination task were compared. The data are displayed in Table 3.9. A 2 (Group) x 2 (Trial Type) mixed repeated measures ANOVA was used. No significant interaction was found between Trial Type x Group: $F(1, 23) = 0.01$, $p = .923$, $\eta_p^2 < .01$. The main effect of Trial Type was also found to be non-significant: $F(1, 23) = 1.89$, p

= .182, η_p^2 = .08. However, there was a significant main effect of Group: $F(1, 23) = 9.02$, p =.006, η_p^2 = .28.

Table 3.9. Accuracy scores for test phase: Experiment 1 (Means and Standard Deviations)

	TD (n = 12)	ASD (n = 13)	Cohen's d
Familiar	.92 (.10)	.73 (.23)	1.07
Novel	.89 (.09)	.70 (.21)	1.18

Note. TD = Typically developing; ASD = Autism spectrum disorder.

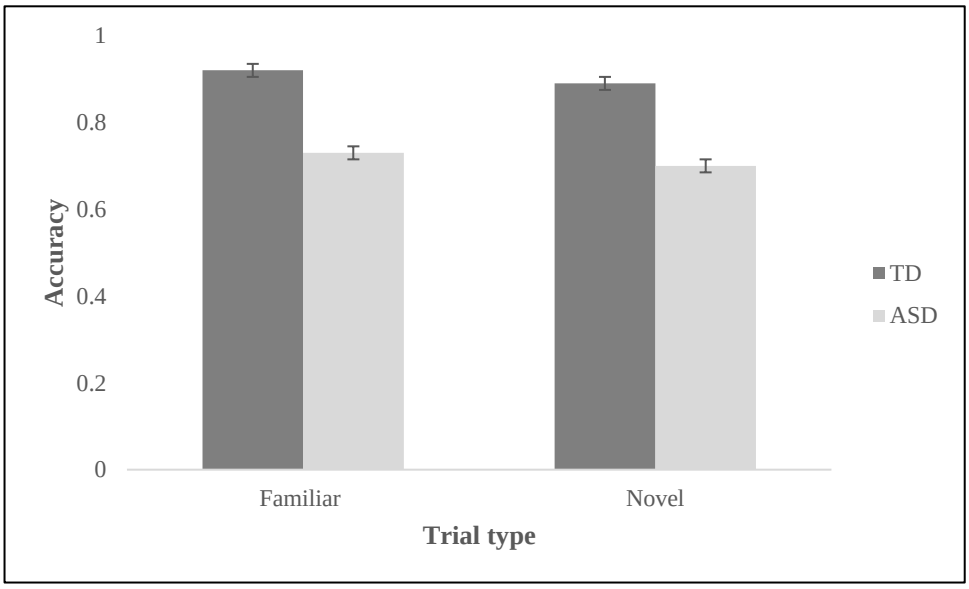

Figure 3.8. Accuracy (M ± SEM) for test phase of Experiment 1. TD = Typically developing; ASD = Autism spectrum disorder.

3.6.3.2. Accuracy compared to chance

Additional tests were carried out to determine whether both groups' performance was significantly above chance for both trial types during the test phase. A one-sample t-test was carried out, with the chance level set at 0.5. Participants in the TD group performed significantly above chance for both trial types (Familiar: $t(11) = 14.23$, $p < .001$, $d = 4.11$; Novel: $t(11) = 14.73$, $p < .001$, $d = 4.25$). Participants in the ASD group also performed

significantly above chance for both trial types (Familiar: $t(12) = 3.67$, $p = .003$, $d = 1.02$; Novel: $t(12) = 3.45$, $p = .005$, $d = 0.96$).

3.6.3.3. Reaction time

Mean reaction times for the correct trials of the test phase were compared across the two trial types; the data are displayed in Table 3.10. A 2 (Trial Type) x 2 (Group) mixed repeated measures ANOVA was used. No significant interaction was found between Trial Type x Group: $F(1, 23) = 2.48$, $p = .129$, $\eta_p^2 = .10$. There was no significant main effect of Trial Type: $F(1, 23) = 1.37$, $p = .253$, $\eta_p^2 = .06$. The main effect of Group was also found to be non-significant: $F(1, 23) = 3.19$, $p = .087$, $\eta_p^2 = .12$.

Table 3.10. Reaction times for correct trials of test phase: Experiment 1 (Means and Standard Deviations)

	TD (n = 12)	ASD (n = 13)	Cohen's d
Familiar	2570.16 (883.94)	2095.88 (1251.89)	0.44
Novel	2971.87 (1150.69)	2037.14 (859.25)	0.92

Note. TD = Typically developing; ASD = Autism spectrum disorder; Reaction time (ms).

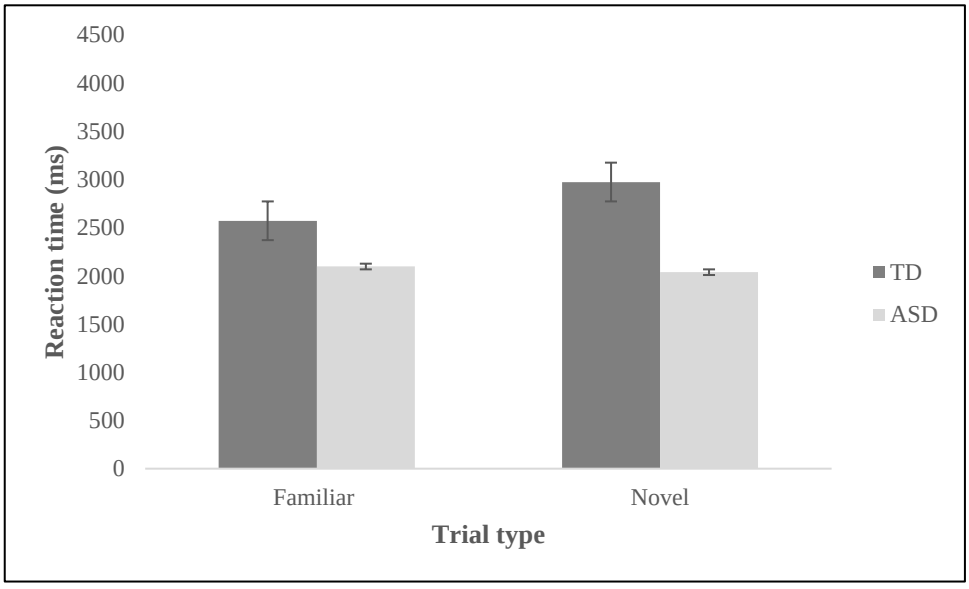

Figure 3.9. Reaction times ($M \pm$ SEM) for correct trials of test phase: Experiment 1. TD = Typically developing; ASD = Autism spectrum disorder.

3.6.3.4. Correlations

Correlational data are presented in Table 3.11. Analysis of both groups' performance revealed a significant negative correlation between age at test and performance for both trial types. Severity of autism symptoms in both groups was negatively correlated with performance in only the novel condition. Both groups' non-verbal ability was positively correlated with performance for both trial types, although the stronger positive correlation found between these variables for the ASD group appears to be the cause of this. Verbal ability correlated with both trial types for both groups, although a stronger correlation was found between verbal ability and performance in the novel trials.

Table 3.11. Correlations between psychometric data and test phase (familiar and novel trials): Experiment 1

	TD		ASD		Both	
	Familiar	Novel	Familiar	Novel	Familiar	Novel
Age (months)	-.36	-.54	-.22	-.35	-.53**	-.62**
SRS	.19	-.04	-.09	-.13	-.41	-.5*
NVA	-.11	-.37	.66*	.72**	.45*	.43*
VA	.32	-.05	.40	.54	.50*	.55**

Note. TD = Typically developing; ASD = Autism spectrum disorder; Both = TD and ASD groups together; SRS = Social Responsiveness Scale (raw score); NVA = Non-verbal ability (Raven's Coloured Progressive Matrices, raw score); VA = Verbal ability (British Picture Vocabulary Scale-III, raw score). ** significant at $p < .01$; * significant at $p < .05$.

3.7. Discussion: Experiment 1

This study adapted a biconditional discrimination task from the non-human relational memory literature (Sanderson et al., 2006; Aggleton et al., 2007), for use with human participants. Participants were trained on pairs of stimuli presented together, each of which included one identical element and one different, and were then presented with a test block in which they were required to discriminate between mirror images of previously presented stimuli. Awareness of the spatial arrangement of the stimuli was not necessary for success in

this task; awareness of the configuration of the stimuli was sufficient to support performance. Previous findings of patterns of impaired and intact performance in configural tasks in ASD and hippocampal damage led to the prediction that individuals with ASD would display intact performance during the test phase of the biconditional discrimination task.

Participants' ability to carry out a simple discrimination task was first analysed. This was included as part of the experimental task, interspersed randomly throughout the main experiment; this involved no configural or spatial component and was included to confirm that participants were able to selectively discriminate between very simple stimuli, and no group differences were predicted. No interaction was found between training block and group, and there was no significant difference found between the groups. Likewise, both groups performed the simple discrimination task well above chance levels. This demonstrated that the ASD group was just as able as the TD group to discriminate between simple stimuli. A main effect of block was found, indicating that the performance of both groups became significantly more accurate as the task went on. There was also no difference between the groups in reaction time, and no interaction between training block and group. However, a main effect of training block was found, demonstrating that both groups became faster at the simple discrimination as the blocks went on. The increasing level of accuracy, and decreased reaction time across the blocks, indicates both groups' increasing familiarity with the stimuli.

These findings negate the possibility that any differential accuracy scores in the experimental task could be attributed to an overall difference in the ability to discriminate between stimuli, in the absence of any structural or configural component. It was in fact found that the accuracy for both groups approached ceiling in the final blocks, demonstrating overall that both groups' memory for the simple stimuli was retained throughout the task.

Therefore, the findings from the simple discrimination task demonstrate that the ASD group have intact visual discrimination between basic stimuli without a configural or structural component.

Accuracy scores for the experimental trials during the training phase were compared. No interaction was found between training block and group. However, a significant group difference was found, with the TD group performing the biconditional discrimination significantly more accurately than the ASD group. However, both groups' accuracy was significantly above chance levels, indicating that both groups were able to learn the biconditional discrimination. A significant difference in accuracy was found for both groups as the training blocks went on; both groups became less accurate across the blocks. This indicates that accuracy decreased for both groups as the blocks became more complex (i.e. as more pairs were integrated).

Mean reaction times for the correct trials of the training phase were also analysed. No interaction was found between training block and group, and there was no overall difference between the groups in reaction time. A difference in reaction time was found for both groups across the blocks, although this shows that the TD group seemed to get significantly slower, whereas the ASD group seemed to get significantly faster, across the blocks. Given the fact that the TD group was more accurate overall in the training phase, this may mean that the ASD group made more random choices and therefore did not think as long about their choices, although this is not supported by the fact that the ASD group also performed significantly above chance levels across the training blocks.

During the training phase, each block could be attempted up to a maximum of three times, if the criteria were not initially met. The number of attempts per block were compared. There was no interaction found between training block and group, and no overall

difference was found between the groups. A significant difference was found in the number of attempts needed for both groups across the training blocks. This showed that both groups found the task more difficult as it became more complex, i.e. when more pairs were introduced. Overall the findings from the training phase demonstrated that both groups were able to learn the biconditional discrimination sufficiently during the training phase, effectively placing them at an equal ability level in preparation for the test phase.

During the test phase, two trial types were presented: during the "familiar" trials, participants were presented with the pairs on which they had previously been trained; during the "novel" trials, participants were presented with mirror images of the previously seen stimuli. The prediction was that, as awareness of the configuration of the stimuli was sufficient in the absence of awareness of the particular spatial arrangement of the stimuli, there would be no difference in accuracy between the groups for either trial type. There was no interaction found between trial type and group, and no difference in accuracy for familiar and novel stimuli for both groups. However, there was a significant overall difference found between the groups: the TD group's performance was significantly more accurate than that of the ASD group, findings which contrast with predictions for this study. However, it was also found that both groups performed the biconditional discrimination test phase significantly above chance levels for both trial types, indicating that the ASD group were able to represent the trained stimuli in memory. No difference was found between the groups in reaction time, and no difference in reaction time was found for either group whether the stimuli were familiar or novel. These findings contrast with predictions that there would be no significant difference in accuracy between the groups but support the assertion that the ASD group are able to learn a biconditional discrimination and use configural information effectively to be able to solve the task.

Analysis of correlational data showed that both age at test and symptoms of ASD correlated negatively with performance, which aligns with the finding of significantly better performance in the TD group. Non-verbal ability was positively correlated with both conditions, which supports the use of the Raven's matrices as a non-verbal matching tool. That it appears to utilise a similar ability as the experimental task would also negate the possible suggestion of the group difference being simply due to the TD group's superior performance at pattern-matching tasks in general. Verbal ability correlated positively with both conditions for both groups; this may indicate that despite the task being effective as a non-verbal test of relational memory, there may be some level of verbalisability of the stimuli, which would put those more verbally-able participants at an advantage for the task.

3.8. Experiment 2: Structural discrimination

3.9. Method

3.9.1. Participants

A total of twenty-six school-aged children were recruited, comprising two groups. Twelve children (nine males and three females) aged between twelve and sixteen with an autism spectrum disorder were recruited from four special educational secondary schools in the London area. All participants in this group had a confirmed diagnosis of an autism spectrum disorder, according to school records of each child's statement of special needs. Where possible, this diagnosis was supported by scores obtained from completion by teachers of the Social Responsiveness Scale (SRS, Constantino, 2005). Participants in this group also had reduced language, which was confirmed by scores obtained from completion by the researcher of the British Picture Vocabulary Scale: Third Edition (BPVS III, Dunn, Dunn, & Styles, 2009).

To form the comparison group, fourteen children (seven boys and seven girls) aged between seven and eleven were recruited from two mainstream primary schools, also in the London area. As reported by the schools, none of these children had any developmental or learning difficulties, which was confirmed by completion by teachers of the SRS. They displayed verbal ability within the typical range for their age; this was confirmed by completion by the researcher of the BPVS-III for each child.

The study was approved by the City, University of London Ethics committee, and informed consent was obtained first from the headteacher of each participating school (Appendices 1 & 2), and then from each child's parent or carer (Appendix 3). Verbal assent was also obtained from each child before each testing session began.

Typically-developing participants were matched on non-verbal ability to participants with an autism spectrum disorder, to within two points on Ravens Coloured Progressive Matrices (RCPM, Raven, 1976). Independent t-tests were carried out using age and psychometric data from each group, which found no significant difference between the groups on non-verbal ability. Significant differences were found between the groups on age, symptoms of autism spectrum disorder, and verbal ability (Table 3.12.).

Table 3.12. Participant characteristics: Experiment 2 (Means and Standard Deviations)

	TD (n = 14)	ASD (n = 12)	t	p	Cohen's d
Age (months)	102.11 (13.85)	169.06 (14.48)	-12.03	< .001	4.73
Range	82-122	151-189			
SRS	21.79 (13.81)	77.71 (27.65)	-5.05	< .001	2.56
Range	3-42	47-111			
NVA	28.36 (4.63)	26.08 (5.63)	1.13	.270	0.44
Range	20-35	19-36			
Percentile	56.5 (26.88)	20.13 (32.37)			
VA	113.64 (12.82)	91.5 (22.32)	3.16	< .001	1.22
Range	96-129	56-136			
Percentile	45.43 (26.17)	2.0 (5.23)			

Note. SRS = Social Responsiveness Scale (raw score), cutoff = 70; NVA = Non-verbal ability (Raven's Coloured Progressive Matrices, raw score); VA = Verbal ability (British Picture Vocabulary Scale-III, raw score).

3.9.2. Materials and Design

As with Experiment 1, stimuli were created specifically for the study by putting together shapes in Microsoft PowerPoint, to create each compound stimulus. Each stimulus was black and white, and measured 10cm x 10cm. Each compound stimulus' left and right halves were distinct from each other in some respect. The pairs which were presented together on screen during the training phase were mirror images of each other (Fig 3.1.). The individual stimuli were presented as a pair on a white screen, using E-Prime software on a 15" Dell touchscreen laptop computer. Each stimulus was either positively or negatively reinforced. If the "correct" stimulus was chosen, positive feedback was given on-screen; specifically a "smiley face" was displayed. If the "incorrect" stimulus was chosen however, negative feedback was displayed; this took the form of a "frowny face" (Fig 3.2).

A practice phase was given initially; this was a test of simple discrimination, in which the participants learned that touching one of the stimuli would result in a specific outcome.

This was administered to confirm that the instructions had been understood by the participant, and in the case of less verbally-able participants, also served to physically model the required behaviour for them so that they could simply copy the experimenter, rather than having to process verbal instructions. After the practice phase was successfully completed, the structural discrimination task was administered. This task consisted of a total of four training blocks and one test block. During the training blocks, the experimental stimuli were successively introduced until all stimuli were presented in random order in the final training block. The test block followed directly after the four training blocks. A simple discrimination task was interspersed throughout the training and test blocks; this was included to ensure that participants were maintaining proper attention to the task, were not pressing stimuli randomly, and that they were able to discriminate between basic stimuli without a configural or structural component (Fig 3.1).

Participants' responses were collected via the touchscreen facility on the computer. Accuracy, reaction times for correct trials, and number of attempts during the training phase were measured. Data were analysed using SPSS 23.0. For the training phase, a 2 x 4 mixed repeated measures design was used, with a repeated measures variable of Training Block (1 – 4). The between-participants variable was Group (TD x ASD). For the test phase, a 2 x 2 mixed repeated measures design, with a repeated measures variable of Trial Type (Familiar x Novel). The between-participants variable was Group (TD x ASD).

3.9.3. Procedure

Participants were tested individually, as part of the normal school day, in a quiet room away from their usual classroom. Participants sat in front of the computer screen and they were asked to confirm that they were happy to begin the task. Participants were provided with simple verbal instructions about the task: "You'll see two pictures together; touching

one of them will show a smiley face and touching the other one will show a sad face, and you need to find the smiley".

On the first practice trial, the experimenter showed the participant how to register a choice of stimulus on the screen, by touching one of the images on the screen itself. During the first practice trial, the experimenter purposefully touched the "incorrect" stimulus on the screen, and the negative feedback (i.e. the "frowny" face) appeared on-screen. The next practice trial was then displayed; this time the experimenter purposefully chose the "correct" stimulus of the pair. This procedure was carried out in order to confirm that the participant fully understood the difference between the positively and negatively reinforced stimuli. On the third practice trial, the participant was encouraged to make the choice themselves. If the participant correctly chose the positively reinforced stimulus, they were then encouraged to "find as many smileys as you can". If the participant did not fully understand the contingencies of the task at this stage, the testing session was terminated. This occurred with one participant from the ASD group and no participants from the TD group.

When it had been confirmed that the participant was happy to continue, the main experiment began. Each trial began with a blank screen which lasted for 1 second, after which a pair of stimuli appeared on-screen. These remained on-screen until the participant had made their choice. The feedback screen was then presented for 1.5 seconds, after which the next trial began. The first training block consisted of 12 trials in total. One pair of structural stimuli (e.g. BW+ WB-) was presented for 10 trials, and one pair of simple stimuli (S+ S-) was presented for 2 trials. The trials were presented in a random order, with the left/right position of the stimuli counterbalanced so that the positively reinforced stimulus appeared on the left side and the right side an equal number of times. The second training block consisted of 14 trials. Here, a new pair of structural stimuli was introduced (e.g. WH+

HW-); this pair was presented for 10 trials. The previous experimental pair (BW+ WB-) was presented for 2 trials, and the simple discrimination task was presented for 2 trials. Trials were again presented in random order. The third training block consisted of 16 trials. Here, another new pair of structural stimuli was introduced (e.g. HB+ BH-) for 10 trials; the previously seen pairs (e.g. WH+ HW-; BW+ WB-) were presented for 2 trials each, and the simple discrimination was presented for 2 trials. Trials were again presented in random order. The fourth and final training block consisted of 14 trials. Each pair of structural stimuli was presented for 4 trials, and the simple discrimination was presented for 2 trials. Trials were again presented in random order. Examples of trial presentation and positive/negative reinforcement protocols are given in Figure 3.13.

Performance criteria for the first three training blocks were set at 80% for experimental trials, and 50% for simple discrimination trials. For the fourth training block the criteria were set at 75% for experiment trials, and 50% for simple discrimination trials. If these criteria were attained on the first attempt, the task moved on automatically to the next block. If these criteria were not reached, the same training block was presented again. The experiment allowed participants to attempt each training block a maximum of three times before it continued to the next block.

After the training phase was completed, the test phase began directly after it. During this block, a total of 40 trials were presented. Each pair of stimuli that had been previously seen ("familiar") was presented for 4 trials each. Participants were also presented with previously unseen pairs of stimuli ("novel"). These consisted of re-pairings of the previously seen stimuli from the training phase (e.g. BW+ HW-; BW+ BH-), creating six new pairs of stimuli, which were presented for 4 trials each. The simple discrimination task was presented for 4 trials. Examples of trial presentation and positive/negative reinforcement protocols are

given in Figure 3.14. On-screen feedback during the test phase was given in the same way as in the training phase. Participants were also given verbal encouragement throughout the task.

Table 3.13. Presentation of trials during training phase: Experiment 2

Training block							
1		2		3		4	
Pair	Trials	Pair	Trials	Pair	Trials	Pairs	Trials
BW+WB-	x10	WH+HW-	x10	HB+ BH-	x10	HB+ BH-	x4
S+ S-	x2	BW+WB-	x2	WH+HW-	x2	WH+HW-	x4
		S+ S-	x2	BW+WB-	x2	BW+WB-	x4
				S+ S-	x2	S+ S-	x2

Note. Pair = Stimuli pair presented together; Trials = Number of trials per block; "+" = Positively reinforced stimulus; "-" = Negatively reinforced stimulus.

Table 3.14. Presentation of trials during test phase: Experiment 2

Familiar		Novel	
Pair	Trials	Pair	Trials
HB+ BH-	x4	BW+ HW-	x4
WH+ HW-	x4	BW+ BH-	x4
BW+ WB-	x4	WH+ WB-	x4
S+ S-	x4	WH+ BH-	x4
		HB+ HW-	x4
		HB+ WB-	x4

Note. Pair = Stimuli pair presented together; Trials = Number of trials per block; "+" = Positively reinforced stimulus; "-" = Negatively reinforced stimulus.

3.10. Results

3.10.1. Simple discrimination task

3.10.1.1. Accuracy

Mean accuracy scores for the simple discrimination task were compared across the four training blocks and the test block; the data are displayed in Table 3.15. A 2 (Group) x 5 (Block) mixed repeated measures ANOVA was used. Mauchly's test indicated that the

assumption of sphericity had been violated ($X^2(9) = 46.53$, $p < .001$), therefore degrees of freedom were corrected using Greenhouse-Geisser estimates of sphericity ($\varepsilon = .49$). No significant interaction was found between Block x Group: $F(1.95, 46.76) = 0.24$, $p = .782$, $\eta_p^2 = .01$. There was also no significant main effect of Group: $F(1, 24) = 1.27$, $p = .272$, $\eta_p^2 = .05$. However, the main effect of Block was found to be significant: $F(1.95, 46.76) = 18.49$, $p < .001$, $\eta_p^2 = .44$.

Table 3.15. Accuracy scores for simple discrimination task: Experiment 2 (Means and Standard Deviations)

Block	TD (*n* = 14)	ASD (*n*=12)	Cohen's *d*
1	.73 (.25)	.65 (.28)	0.30
2	.96 (.13)	.90 (.21)	0.34
3	.94 (.14)	.92 (.21)	0.11
4	.99 (.04)	.90 (.21)	0.60
Test	.98 (.07)	.94 (.11)	0.43

Note. TD = Typically developing; ASD = Autism spectrum disorder.

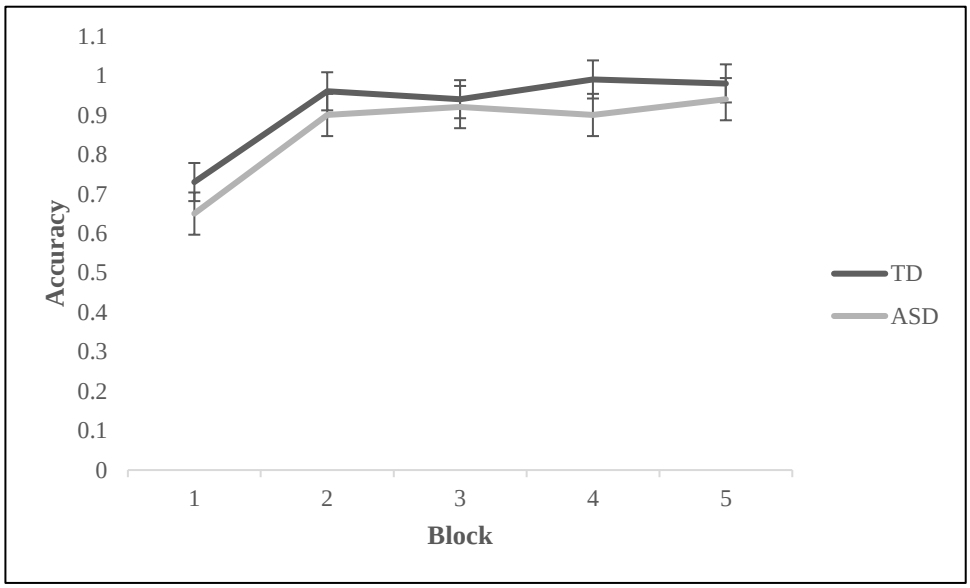

Figure 3.10. Accuracy (*M* ± SEM) for simple discrimination trials of Experiment 2. TD = Typically developing; ASD = Autism spectrum disorder.

3.10.1.2. Accuracy compared to chance

Additional tests were carried out to determine whether the performance for the simple discrimination task was significantly above chance for both groups across the blocks. A one-sample t-test was used, with the chance level set at 0.5. Participants in the TD group performed significantly above chance across all the blocks (Block 1: $t(13) = 3.48$, $p = .004$, $d = 0.93$; Block 2: $t(13) = 13.0$, $p < .001$, $d = 3.47$; Block 3: $t(13) = 11.7$, $p < .001$, $d = 3.13$; Block 4: $t(13) = 40.18$, $p < .001$, $d = 9.74$; Test Block: $t(13) = 27.0$, $p < .001$, $d = 7.22$). Participants in the ASD group performed significantly above chance in all blocks other than the first training block (Block 1: $t(11) = 1.87$, $p = .088$, $d = 0.54$; Block 2: $t(11) = 6.73$, $p < .001$, $d = 1.94$; Block 3: $t(11) = 6.95$, $p < .001$, $d = 2.01$; Block 4: $t(11) = 6.73$, $p < .001$, $d = 1.94$; Test Block: $t(11) = 13.40$, $p < .001$, $d = 3.87$).

3.10.1.3. Reaction time

Mean reaction times for the correct trials of the simple discrimination which was interspersed throughout the structural discrimination task were compared across the four training blocks; the data are displayed in Table 3.16. A 2 (Group) x 5 (Block) mixed repeated measures ANOVA was used. Mauchly's test indicated that the assumption of sphericity had been violated ($X^2(9) = 38.6$, $p = .001$), therefore degrees of freedom were corrected using Greenhouse-Geisser estimates of sphericity ($\varepsilon = .51$). No significant interaction was found between Block x Group: $F(2.04, 48.85) = 0.44$, $p = .649$, $\eta_p^2 = .02$. There was also no significant main effect of Group: $F(1, 24) = 0.18$, $p = .679$, $\eta_p^2 = .01$. However, the main effect of Block was found to be significant: $F(2.04, 48.85) = 5.76$, $p = .005$, $\eta_p^2 = .19$.

Table 3.16. Reaction times for correct trials of simple discrimination task: Experiment 2 (Means and Standard Deviations)

Block	TD (*n* = 14)	ASD (*n*=12)	Cohen's *d*
1	2377.35 (1528.24)	2385.88 (1291.32)	0.00
2	1800.28 (646.98)	2016.09 (810.1)	0.29
3	1530.56 (367.11)	1905.66 (1169.79)	0.43
4	1443.46 (329.25)	1444.35 (521.71)	0.00
Test	1571.13 (632.1)	1403.19 (848.59)	0.22

Note. TD = Typically developing; ASD = Autism spectrum disorder; Reaction time (ms).

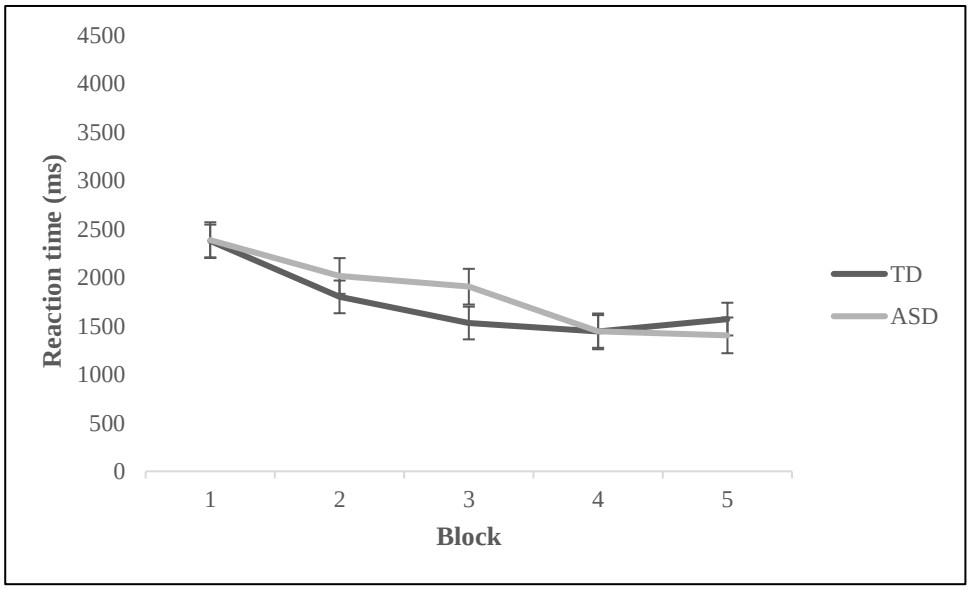

Figure 3.11. Reaction times (*M* ± SEM) for simple discrimination task of Experiment 2. TD = Typically developing; ASD = Autism spectrum disorder.

3.10.2. Training phase

3.10.2.1. Accuracy

Mean accuracy scores for the structural discrimination task were compared across the four training blocks. The data are displayed in Table 3.17. A 2 (Group) x 4 (Block) mixed repeated measures ANOVA was used. No significant interaction was found between Block x Group: $F(3, 72) = 0.51$, $p = .648$, $\eta_p^2 = .02$. No significant main effect of Group was found:

$F(1, 24) = 3.12$, $p = .090$, $\eta_p^2 = .12$. However, there was a significant main effect of Block: $F(3, 72) = 7.45$, $p = .002$, $\eta_p^2 = .24$.

Table 3.17. Accuracy scores for training phase: Experiment 2 (Means and Standard Deviations)

Block	TD (n = 14)	ASD (n = 12)	Cohen's d
1	.89 (.11)	.74 (.21)	0.89
2	.80 (.21)	.69 (.18)	0.56
3	.70 (.20)	.62 (.15)	0.45
4	.71 (.20)	.64 (.26)	0.30

Note. TD = Typically developing; ASD = Autism spectrum disorder.

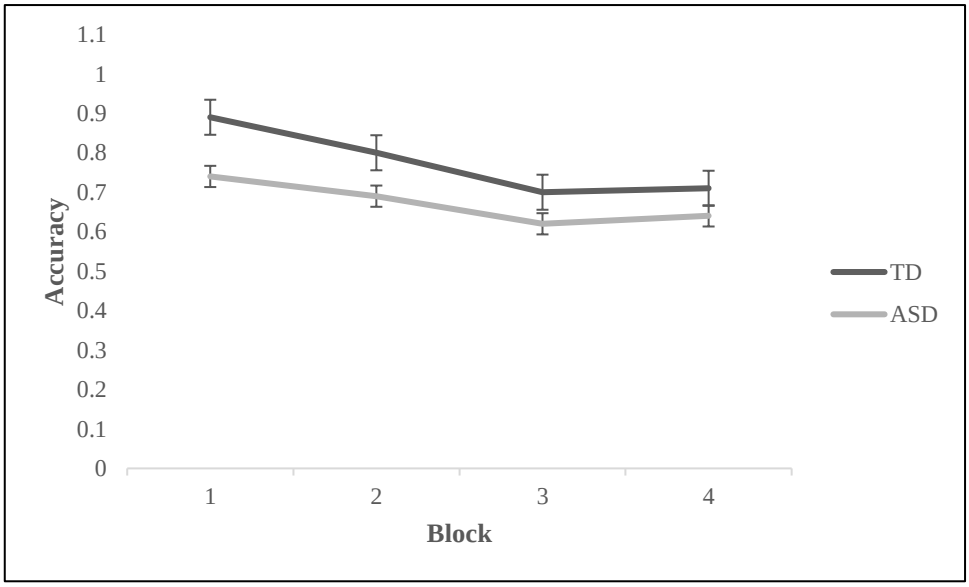

Figure 3.12. Accuracy ($M \pm$ SEM) for training phase: Experiment 2. TD = Typically developing; ASD = Autism spectrum disorder.

3.10.2.2. Accuracy compared to chance

Additional tests were carried out to determine whether the performance for structural discrimination training was significantly above chance for both groups across the blocks. A one-sample t-test was carried out, with the chance level set at 0.5. Participants in the TD group performed significantly above chance in all training blocks (Block 1: $t(13) = 13.95$, $p < .001$, $d = 3.73$; Block 2: $t(13) = 5.42$, $p < .001$, $d = 1.45$; Block 3: $t(13) = 3.75$, $p = .002$, $d =$

1.00; Block 4: $t(13) = 3.99$, $p = .002$, $d = 1.07$). Participants in the ASD group performed significantly above chance across the first three training blocks (Block 1: $t(11) = 3.99$, $p = .002$, $d = 1.15$; Block 2: $t(11) = 3.68$, $p = .004$, $d = 1.06$; Block 3: $t(11) = 2.65$, $p = .022$, $d = 0.77$). However, their performance during the fourth training block was not significantly higher than chance levels ($t(11) = 1.86$, $p = .090$, $d = 0.54$).

3.10.2.3. Reaction time

Mean reaction times for the correct trials of the structural discrimination task were compared across the four training blocks; the data are displayed in Table 3.18. A 2 (Group) x 4 (Block) mixed repeated measures ANOVA was used. Mauchly's test indicated that the assumption of sphericity had been violated ($X^2(5) = 36.51$, $p > .001$), therefore degrees of freedom were corrected using Greenhouse-Geisser estimates of sphericity ($\varepsilon = .52$). No significant interaction was found between Block x Group: $F(1.57, 37.6) = 3.13$, $p = .067$, $\eta_p^2 = .12$, and there was no main effect of Group: $F(1, 24) = 0.6$, $p = .446$, $\eta_p^2 = .02$, or Block: $F(1.57, 37.6) = 0.26$, $p = .722$, $\eta_p^2 = .01$.

Table 3.18. Reaction times for correct trials of training phase: Experiment 2 (Means and Standard Deviations)

Block	TD (n = 14)	ASD (n = 12)	Cohen's d
1	2033.04 (468.44)	2341.32 (1079.52)	0.37
2	2189.37 (766.56)	2164.04 (755.79)	0.03
3	2607.8 (1439.45)	1888.66 (508.93)	0.67
4	2606.88 (1616.2)	2042.01 (691.76)	0.45

Note. TD = Typically developing; ASD = Autism spectrum disorder; Reaction time (ms).

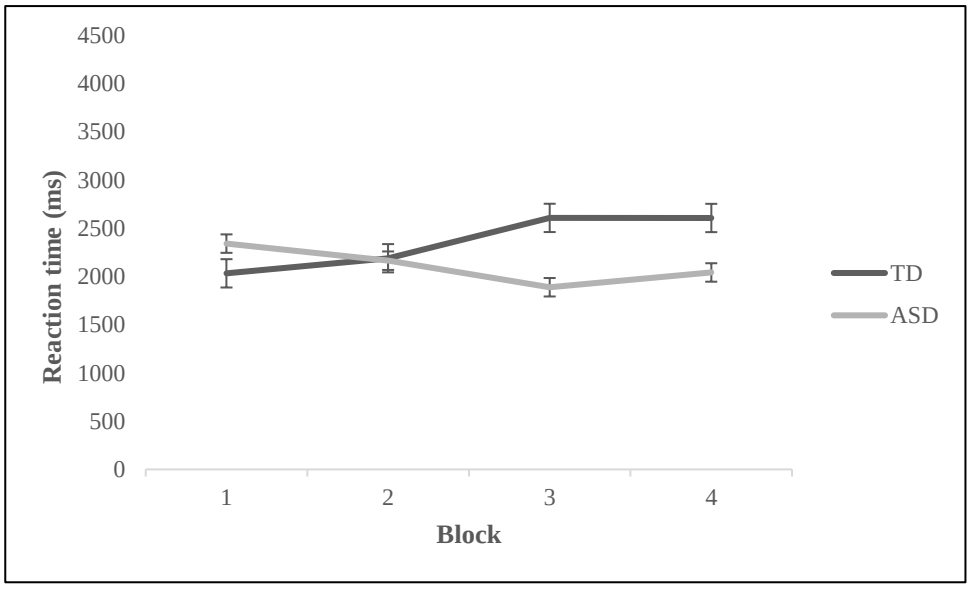

Figure 3.13. Reaction times (*M* ± SEM) for correct trials of training phase: Experiment 2. TD = Typically developing; ASD = Autism spectrum disorder.

3.10.2.4. Number of attempts

The mean number of attempts for the biconditional discrimination task were compared across the four training blocks. The data are displayed in Table 3.19. A 2 (Group) x 4 (Block) mixed repeated measures ANOVA was used. No significant interaction was found between Block x Group: $F(3, 72) = 0.62$, $p = .599$, $\eta_p^2 = .03$. There was also no significant main effect of Group: $F(1, 24) = 2.20$, $p = .151$, $\eta_p^2 = .08$. However, the main effect of Block was found to be significant: $F(3, 72) = 6.05$, $p = .001$, $\eta_p^2 = .20$.

Table 3.19. Number of attempts per training block: Experiment 2 (Means and Standard Deviations)

Block	TD (*n* = 14)	ASD (*n* = 12)	Cohen's *d*
1	1.43 (.65)	1.83 (.84)	0.53
2	1.64 (.84)	2.17 (.84)	0.63
3	2.07 (.83)	2.50 (.80)	0.53
4	2.29 (.91)	2.33 (.99)	0.04

Note. TD = Typically developing; ASD = Autism spectrum disorder.

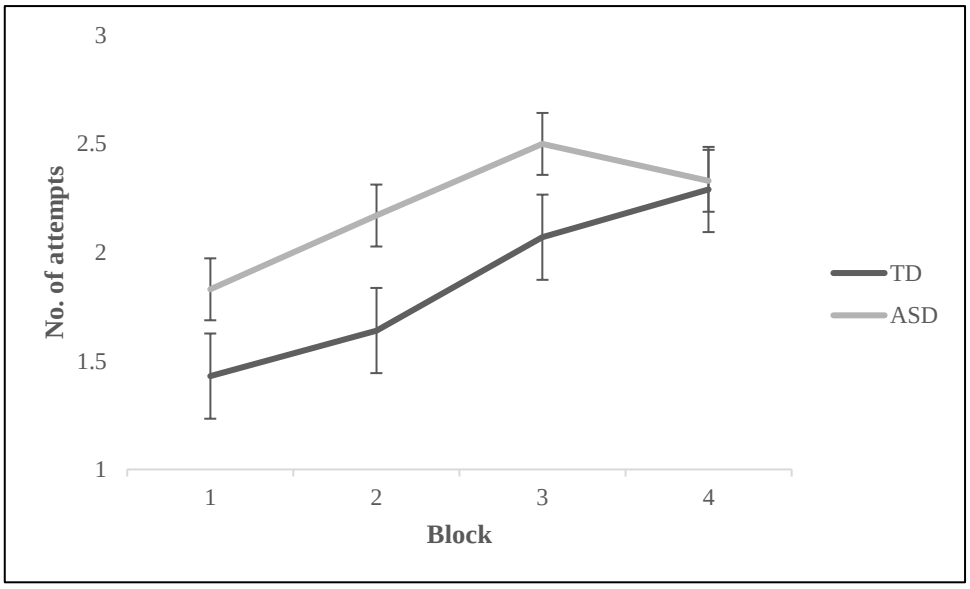

Figure 3.14. Number of attempts (*M* ± SEM) for each training block of Experiment 2. TD = Typically developing; ASD = Autism spectrum disorder.

3.10.3. Test phase

3.10.3.1. Accuracy

Mean accuracy scores during the test phase were compared across the two trial types (Familiar and Novel); the data are displayed in Table 3.20. A 2 (Trial Type) x 2 (Group) mixed repeated measures ANOVA was used. No significant interaction was found between Trial Type x Group: $F(1, 24) = 2.78$, $p = .109$, $\eta_p^2 = .10$. There was no significant main effect of Trial Type: $F(1, 24) = 0.19$, $p = .667$, $\eta_p^2 = .01$. The main effect of Group was also found to be non-significant: $F(1, 24) = 0.03$, $p = .859$, $\eta_p^2 < .01$.

Table 3.20. Accuracy scores for test phase: Experiment 2 (Means and Standard Deviations)

	TD (*n* = 14)	ASD (*n* = 12)	Cohen's *d*
Familiar	.67 (.28)	.70 (.22)	0.12
Novel	.71 (.22)	.64 (.25)	0.30

Note. TD = Typically developing; ASD = Autism spectrum disorder.

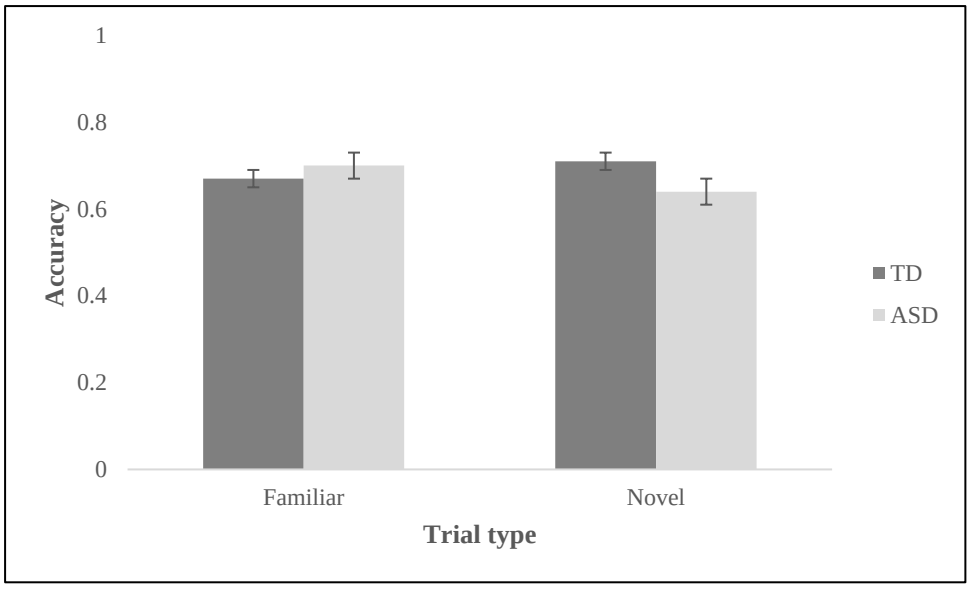

Figure 3.15. Accuracy (*M* ± SEM) for test phase: Experiment 2.
TD = Typically developing; ASD = Autism spectrum disorder.

3.10.3.2. Accuracy compared to chance

Additional tests were carried out to determine whether both groups' performance was significantly above chance for both trial types during the test phase. A one-sample t-test was carried out, with the chance level set at 0.5. Participants in the TD group performed significantly above chance for both trial types (Familiar: $t(13) = 2.26$, $p = .042$, $d = 0.6$; Novel: $t(13) = 3.56$, $p = .004$, $d = 0.95$). Participants in the ASD group performed significantly above chance only for the previously seen pairs (Familiar: $t(11) = 3.15$, $p = .009$, $d = 0.91$; Novel: $t(11) = 1.93$, $p = .08$, $d = 0.56$).

3.10.3.3. Reaction time

Mean reaction times for correct trials of the test phase of the structural discrimination task were compared; the data are displayed in Table 3.21. A 2 (Group) x 2 (Trial Type) mixed repeated measures ANOVA was used. No significant interaction was found between Trial Type x Group: $F(1, 24) = 0.00$, $p = .971$, $\eta_p^2 < .01$. The main effects of Group and Trial

Type were also found to be non-significant: Group: $F(1, 24) = 1.73$, $p = .201$, $\eta_p^2 = .07$; Trial Type: $F(1, 24) = 2.74$, $p = .111$, $\eta_p^2 = .10$.

Table 3.21. Reaction times for correct trials of test phase: Experiment 2 (Means and Standard Deviations)

	TD (n = 14)	ASD (n = 12)	Cohen's d
Familiar	2581.89 (1878.93)	1886.2 (854.14)	0.48
Novel	2844.11 (1561.89)	2137.08 (954.17)	0.55

Note. TD = Typically developing; ASD = Autism spectrum disorder; Reaction time (ms).

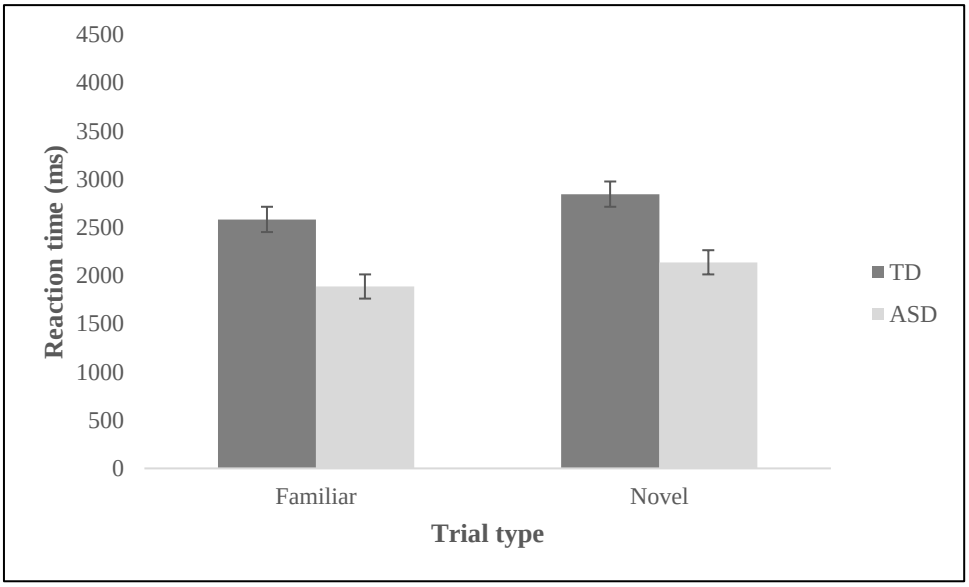

Figure 3.16. Reaction times ($M \pm$ SEM) for correct trial of test phase: Experiment 2. TD = Typically developing; ASD = Autism spectrum disorder.

3.10.3.4. Correlations

Correlational data are presented in Table 3.22. A significant positive correlation was found between age at test and performance, for only the TD group. No correlation was found between severity of autism symptoms and performance of both groups. Both groups' non-verbal ability was positively correlated with performance in both conditions. No correlation was found between verbal ability and performance for both groups. Performance on familiar and novel trials were positively correlated with each other.

Table 3.22. Correlations between psychometric data and test phase (familiar and novel trials): Experiment 2

	TD		ASD		Both	
	Familiar	Novel	Familiar	Novel	Familiar	Novel
Age (months)	.61*	.65*	.12	.22	.22	.02
SRS	.18	.34*	.01	-.03	.04	-.03
NVA	.83**	.87**	.68*	.92**	.71**	.90**
VA	.51	.48	.04	-.22	.16	.12
Familiar	-	.91**	-	.66*	-	.77**
Novel	. 91**	-	.66*	-	.77**	-

Note. TD = Typically developing; ASD = Autism spectrum disorder; Both = TD and ASD groups together; SRS = Social Responsiveness Scale (raw score); NVA = Non-verbal ability (Raven's Coloured Progressive Matrices, raw score); VA = Verbal ability (British Picture Vocabulary Scale-III, raw score). ** significant at $p < .01$; * significant at $p < .05$.

3.11. Discussion: Experiment 2

This study adapted a structural discrimination task from the non-human relational memory literature (Sanderson et al., 2006; Aggleton et al., 2007), for use with human participants. This was a configural discrimination task, but unlike the biconditional discrimination task, contained an extra component. The training pairs were mirror images of each other, and therefore contained identical elements, but each compound stimulus contained a different spatial arrangement of those elements. This meant that awareness of the configuration of the stimuli was not sufficient to support performance; success was dependent on the participant's awareness of the spatial arrangement of the stimuli. Previous findings of patterns of impaired and intact performance in configural tasks in ASD and hippocampal damage led to the prediction that the performance of individuals with ASD would be significantly impaired during the novel trials of the test phase of the task.

As with Experiment 1, a simple discrimination task was included as part of the main experiment; trials were randomly interspersed through the training and test phases. Again, as success in this task was not dependent upon the awareness of any configural or structural

component to the reinforced stimuli, no differences between the groups were predicted, and the findings confirm this. No interaction was found between block and group, and there was no significant difference found between the groups, demonstrating that, as with Experiment 1, the ASD group was just as able as the TD group to discriminate between simple stimuli. The TD group performed the simple discrimination significantly above chance for all blocks, and the ASD group performed above chance for all except the first training block, indicating effective learning of the simple stimuli.

A main effect of block was found, indicating that both groups became significantly more accurate at the simple discrimination task as the blocks went on. There was also no difference between the groups in their reaction time, and no interaction between block and group. However, a main effect of training block was found, demonstrating that both groups became faster at the simple discrimination as the blocks went on. The increasing level of accuracy, and decreased reaction time across the blocks, indicates, as with the groups who participated in Experiment 1, a significantly increasing familiarity with the simple stimuli.

During the training phase of the main experiment, participants were trained on pairs of stimuli that were mirror images of each other. There were no group differences in the level of accuracy for the structural stimuli during this phase. However, it was found that performance for both groups significantly decreased in accuracy as the blocks went on, reflecting the increase in the level of complexity as new pairs were added. When comparing both groups' performance to chance levels, it was found that the TD group performed significantly above chance levels across all training blocks. However, during the fourth training block, in which all previously trained pairs were shown again, for four trials each, the ASD group did not perform significantly above chance levels. No difference in reaction time was found between the groups, and no significant increase in reaction time for either group

across the training blocks, regardless of the level of complexity of the blocks. There was also no significant difference found between the groups in the number of attempts taken for each training block, although it was found that both groups required significantly more attempts as the blocks went on.

During the test phase, no significant difference was found between the groups in the level of accuracy, regardless of whether the stimuli were familiar or novel pairings. For both groups, there was also no difference found in accuracy between the two trial types. When comparing the level of accuracy to chance however, it was found that while both groups discriminated the familiar pairs significantly above chance level, participants in the ASD group performance at chance during the novel trials. No group difference was found in reaction time during the test phase, as well as no difference in reaction time for both groups across both trial types. In contrast with Experiment 1, analysis of correlational data found no relation between verbal ability and performance. This may indicate that the structural discrimination stimuli were less verbalisable than the stimuli in Experiment 1, and therefore a higher level of verbal ability would not provide an inherent advantage to the task.

3.12. Discussion: Experiments 1 and 2

The current study adapted two tests of configural discrimination from studies of relational memory already carried out with non-human animals (Sanderson et al., 2006; Aggleton et al., 2007). Experiment 1 administered a biconditional discrimination task to participants; to be successful in this task, an awareness of how the stimuli were configured (i.e. which elements made up the stimulus) was required. Experiment 2 administered a structural discrimination task to participants; this task is a subset of configural discrimination, which like the biconditional discrimination task, requires an awareness of the configuration of stimuli but also includes a spatial component. Both stimuli have the same configuration of

elements but are arranged differently spatially; to be able to correctly choose the reinforced stimulus, an awareness of this spatial arrangement is necessary. This kind of task is thought to be processed by the hippocampus (Aggleton & Pearce, 2001), and led to the prediction for the current study that, as individuals with ASD have previously displayed a similar patterning of memory impairments as those with compromised hippocampal function, they would display intact performance in the biconditional discrimination task, while being significantly impaired in the structural discrimination task.

The prediction for the biconditional discrimination task was partly confirmed. During the training phase, the TD group was found to be significantly more accurate overall, although both groups were found to perform the discrimination significantly above chance. This shows that the ASD group, although displaying significantly poorer performance, were still able to learn the discrimination successfully. The same pattern was found for the test phase of the biconditional discrimination task. The TD group was found to be significantly more accurate overall, whilst both groups' performance for familiar and novel trials was significantly above chance levels, indicating that the ASD group had sufficiently encoded the configuration of the stimuli to allow them to solve the task. The discovery of a difference in the overall performance between the groups appears to contrast with findings from previous research with non-human animals, in which rats with hippocampal lesions were able to learn a biconditional discrimination at a comparable level to typical animals (Sanderson et al, 2006; Aggleton et al., 2007). However, the current study's finding that the ASD group performed the biconditional discrimination well above chance levels appears to support the prediction that individuals with ASD would be able to learn this discrimination, and use this information to solve the task.

In contrast, the findings from the structural discrimination task appear to conflict with predictions. During the training phase, there was found to be no difference in performance between the groups. However, whilst the TD group performed the discrimination well above chance levels for all the training blocks, the ASD group performed at chance for the final training block, suggesting that the ASD group were not able to learn the discrimination as readily. During the test phase, no overall group differences were found, indicating that the ASD group had been sufficiently trained on the discriminations to be able to use the information during the test phase. The finding that the ASD group performed at chance levels during the final training block is mitigated here by the finding that they performed the familiar trials during the test phase well above chance and at a level comparable with the performance of the TD group.

Planned comparisons for the two trial types however highlighted a difference. For the familiar trials (stimulus pairs on which they had been previously trained), both groups performed significantly above chance. However, for the novel stimuli, (stimuli from the training phase which were re-paired to create new pairs), only the TD group performed significantly above chance. This appears to indicate that, while the groups' overall performance was at comparable levels, the ASD group seemed to display some difficulty with the novel pairs, and therefore were potentially less sensitive to the spatial component of the task.

Participants were also presented with a concurrent test of simple discrimination which was interspersed throughout each main experiment. This task required them to discriminate between simple stimuli, in the absence of any structural or configural component. This was included to control for any potential difference in general visual discrimination of stimuli. Both groups displayed a similar level of ability in this task, indicating no problems with basic

visual discrimination for individuals with ASD and reduced language. This demonstrated that any differences in accuracy for experimental trials could not be accounted for by differences in basic visual discrimination.

The dissociation found in the correlational analysis of verbal ability and performance raises a question about the suitability of the methodology for use with human participants. Verbal ability was found to be related to performance in the biconditional discrimination task but not the structural discrimination task. It may be that the stimuli in the biconditional discrimination task were more easily verbalisable, which placed the less-verbally able participants at a disadvantage from the beginning. In contrast, the structural stimuli may have been more difficult to verbally label, as each compound stimulus contained identical elements, therefore placing both groups on a level footing, regardless of language ability. In this way, it may be that the structural discrimination task was a more effective measure of relational memory across the spectrum, and that future research with human participants should look to administer tasks utilising more abstract stimuli.

The findings from Experiments 1 and 2 demonstrate these tasks to be effective tests of relational memory, suitable for use with participants across the spectrum, due to the minimal verbal instructions involved. However, the findings largely appear to contrast with the research from participants with hippocampal dysfunction, potentially indicating that individuals with ASD may not in fact be cognitively similar to those with hippocampal damage. Despite this, the fact that the ASD participants performed at chance levels during the condition in which awareness of the spatial configuration was a factor in success, may point to hippocampal function in these individuals being more selectively compromised.

Chapter 4: Study 2: Transitive inference in ASD

4.1 Introduction

The characteristic memory patterning previously found in high-functioning individuals with ASD suggests that they have an impairment in relational memory. As previous research has mostly been carried out using verbalisable material such as lists of words, the current study aimed to measure relational memory non-verbally in ASD. This was done using a non-verbal test of relational memory, adapted from the non-human animal research, for use with human participants at any level of functioning. The paradigm utilised in the current study was a test of transitive inference, which requires the flexible processing of relations between elements of visual stimuli, and which has been shown to be an effective non-verbal measure of hippocampal function.

4.2 Transitive inference

Transitive inference involves the encoding of the relationships between elements of visual stimuli in a flexible way, so that those relations can be subsequently utilised. For example, if we learn that A > B, and B > C, we can infer that A > C. The explicit ability to solve this kind of task has been demonstrated in typically-developing children from around age six (Wright & Smailes, 2015), but sensitivity to these kinds of relations has also been demonstrated in very young typically-developing children. Mou, Province, and Luo (2014) administered a preferential looking task to sixteen-month old infants, to test their level of awareness of transitive relations. Participants were presented with the experimenter who was sitting behind two objects, one red (A) and one yellow (B). The experimenter reached for object A for multiple trials, thereby familiarising the participant to their preference for one of the two objects. Object B was then paired with a green object (C), and the experimenter

reached for object B for multiple trials, familiarising the participant to their preference for one of those two objects. After the familiarisation phase, a test phase was presented, pairing object A with object C. This pair had not been previously seen together, but a correct inference about the experimenter's preference between these two objects would lead to the expectation that the experimenter would choose A over C, as A was preferred over B, and B over C. Typically-developing infants looked longer when the experimenter chose C over B, demonstrating that they were aware that this was an unexpected event, and therefore that they were aware of the specific relation between A > C.

Evidence that the hippocampus has an important role in transitive inference ability has been shown in several studies with humans, including Nagode and Pardo (2002), who administered a transitive inference task to typical adults using pairs of faces whilst scanning them using PET, and demonstrated hippocampal activation during transitive inference. In addition, Smith and Squire (2005), who trained typical adults and adults with hippocampal damage on pairs of Japanese symbols, found transitive inference performance to be impaired by hippocampal damage. These findings are mirrored in the animal literature: Van Elzakker, O'Reilly, and Rudy (2003) found that whilst typical rats were able to solve a transitive inference task involving odour discrimination, rats with hippocampal damage were impaired at the same task. Hippocampal lesions have also been found to disrupt the performance of pigeons in a transitive inference task involving visual stimuli (Lazareva, Kandray, & Acerbo, 2015). Despite other evidence demonstrating the rostro-lateral prefrontal cortex to be more strongly activated than the hippocampus during a visual transitive inference task (Wendelken & Bunge, 2010), it does appear that hippocampal damage has a detrimental effect on performance in this kind of task, which has led to the conclusion that the hippocampus supports the representational flexibility required to be successful at transitive inference.

This kind of flexible cognition can also be seen to extend to the domain of social cognition, and transitive inference may be essential for success in social interactions. For instance, for a successful social interaction to take place between a group of people, there must be a basic level of awareness of the relations between the people in the group (e.g. who already knows one another, whether anyone is socially dominant, what preferences people in the group may have etc.) (Rubin, Watson, Duff, & Cohen, 2014). Evidence of awareness of these kinds of social relations has been found in early human development. One-year old infants were shown videos depicting dominance interaction behaviour between three animal puppets. They were then shown a video of an interaction between puppets that had been previously seen, but not together. These interactions were either congruous or not with the original dominance interaction with which they were presented. Infants looked significantly longer to the incongruous interactions, demonstrating their awareness of this as an unexpected event, and therefore of the social hierarchy of the puppets (Gazes, Hampton, & Lourenco, 2017).

Awareness of social relations has also been found to aid transitive inference in non-human animals. Maclean, Merritt, and Brannon (2008) administered a transitive inference task using visual stimuli to two different species of lemur: ringtailed lemurs, who are highly social animals, and less social mongoose lemurs. The ringtailed lemurs' performance was significantly better than that of the mongoose lemurs, which led to the conclusion that their superior performance occurred as a result of their high sociability. This was also found by Bond, Wei, and Kamil (2010), who tested four different species of corvid on a visual transitive inference task. Pinyon jays, who were the most social of the species tested, were found to be the most accurate on transitive pairs.

Libben and Titone (2008) postulate two ways of solving the transitive inference task. One of these is by employing a conjunctive strategy, in which the entire hierarchy is encoded. Another way of solving these tasks is via an associative strategy, in which different associative strengths are assigned to the different stimuli, based on their position in the sequence. This strategy would have the effect of making transitive pairs containing the end stimuli much easier than the middle pairs; for example in the A+E- pair, A is always reinforced and E is never reinforced, whereas in the B+D- pair, both stimuli have been equally reinforced (i.e. A+B-, but B+C-, and C+D-, but D+E-), causing both B and D to be assigned the same associative strength. This means that investigation of the level of accuracy in the BD pair can potentially highlight the strategy being used by participants. Typical adult humans have been found to use a conjunctive strategy in carrying out such tasks (Moses, Villate, & Ryan, 2006), whereas non-human animals tend to use an associative, pair-by-pair strategy (von Fersen, Wynne, Delius, & Staddon, 1991), suggesting that language is important in the construction of hierarchical strategies. This would suggest that individuals with reduced language abilities would also tend to use an associative strategy.

Several studies demonstrate a link between transitive inference performance and ASD. Solomon et al. (2015) carried out a transitive inference task with high-functioning adolescents with ASD, who were matched with typically-developing adolescents. Participants were trained on adjacent pairs of stimuli from an overall hierarchy consisting of coloured ovals, while they were scanned using fMRI. The group with ASD were found to perform the task just as well as the typical group; however, results from fMRI showed that functional connectivity between the hippocampus and caudate was positively associated with transitive inference performance for only the ASD group. Silverman, Gastrell, Karras, Solomon, and Crawley (2013) administered a transitive inference task to mice who had been bred as an animal model of ASD, in which adjacent pairs of visual stimuli were presented on

a touchscreen. The ASD-model mice were able to learn the training pairs to a level comparable with that of a group of typical mice, but were found to be impaired in discriminating between the transitive pair A-E. Solomon, Frank, Smith, Ly, and Carter (2011) found that high-functioning adults with ASD used a conjunctive strategy to solve a transitive inference task. Although this appears to be in contrast with other findings from ASD, it may point to language ability in ASD as a mitigating factor in success on the task.

The following study aimed to investigate whether the problems previously found with transitive inference in ASD are borne out in individuals with ASD and reduced language. Previous findings that transitive inference is diminished by hippocampal damage, along with the social difficulties seen in ASD, predicted diminished performance in transitive inference tasks in individuals with ASD. Another prediction was that, in the event that they were able to solve a transitive inference task, individuals with ASD would not be as likely to develop a conjunctive strategy based on the overall hierarchy of the stimuli.

4.3. Experiment 3: Transitive inference

4.4. Method

4.4.1. Participants

A total of forty-nine school-aged children were recruited, comprising two groups. Twenty-five children (nineteen males and six females) aged between eleven and sixteen with an autism spectrum disorder were recruited from four special educational secondary schools in the London area. All participants in this group had a confirmed diagnosis of an autism spectrum disorder, according to school records of each child's statement of special needs. Where possible, this diagnosis was supported by scores obtained from completion by teachers of the Social Responsiveness Scale (SRS, Constantino, 2005). Participants in this group also

had reduced language ability, which was confirmed by scores obtained from completion by the researcher of the British Picture Vocabulary Scale: Third Edition (BPVS-III, Dunn, Dunn, & Styles, 2009).

To form the comparison group, twenty-four children (twelve boys and twelve girls) aged between six and eleven were recruited from two mainstream primary schools, also in the London area. As reported by the schools, none of these children had any developmental or learning difficulties, which was confirmed by completion by teachers of the SRS, and displayed verbal ability within the typical range for their age; this was confirmed by completion by the researcher of the BPVS-III for each child.

The study was approved by the City, University of London Ethics committee, and informed consent was obtained first from the headteacher of each participating school (Appendices 1 & 2), and then from each child's parent or carer (Appendix 3). Verbal assent was also obtained from each child before each testing session began.

Typically-developing participants (TD group) were matched on non-verbal ability to participants with an autism spectrum disorder (ASD group), to within three points on Ravens Coloured Progressive Matrices (RCPM, Raven, 1958). Independent t-tests were carried out using age and psychometric data from each group, which found no significant difference between the groups on non-verbal ability. Significant differences were found between the groups on age and verbal ability. Table 4.1 shows age and psychometric data for both groups.

Table 4.1. Participant characteristics: Experiment 3 (Means and Standard Deviations)

	TD (*n* =24)	ASD (*n* =25)	*t*	*p*	Cohen's *d*
Age (months)	100.2 (14.13)	163.38 (14.3)	-15.55	< .001	4.44
Range	83-131	142-190			
SRS	20.46 (15.16)	77.35 (22.28)	-10.04	< .001	2.99
Range	0-62	36-111			
NVA	26.63 (5.42)	24.36 (5.77)	1.42	.163	0.41
Range	15-35	15-34			
Percentile	48.79 (33.8)	12.57 (22.27)			
VA	108.5 (16.02)	79.36 (21.22)	5.41	< .001	1.55
Range	74-139	34-122			
Percentile	49.92 (27.3)	.57 (1.5)			

Note. SRS = Social Responsiveness Scale (raw score), cutoff 70; NVA = Non-verbal ability (Raven's Coloured Progressive Matrices, raw score); VA = Verbal ability (British Picture Vocabulary Scale-III, raw score).

4.4.2. Materials and Design

The stimuli used were based on a paradigm developed by Maclean et al. (2008). The original study used a set of seven stimuli, which were presented in pairs, to create six training pairs. However, the current study used only five of the original stimuli, to create four training pairs (Fig 4.1). This was done to limit the time required for participants to concentrate on the experiment, particularly for those with attentional difficulties.

The individual stimuli were presented as a pair on a white screen, using E-Prime software on a 15" Dell touchscreen laptop computer. Pairs of stimuli were presented in sequential order. Participants were required to find the "higher-ranked" of the pair by touching it on-screen (i.e. A > B, and B > C etc.). If the "higher ranked" stimulus was chosen, positive feedback was given on-screen; specifically a "smiley face" was displayed. If the "incorrect" stimulus was chosen however, negative feedback was displayed; this took the form of a "frowny face" (Fig 3.2).

A practice phase was given initially, to confirm that the instructions had been understood by the participant. In the case of less verbally-able participants, this phase also served to model the required behaviour for them so that they could simply copy the experimenter, rather than having to process verbal instructions. After this, three training blocks were presented; these increased in complexity with each block. After the training blocks, one test block followed directly after. Following the main transitive inference task, participants were also given a task to measure their awareness of the overall ordinal sequence of stimuli.

Participants' responses were collected via the touchscreen facility on the computer. During the training phase, accuracy, reaction time, and number of attempts were measured. During the test phase, accuracy and reaction time were measured. During the test of awareness of the ordinal sequence, the distance from the actual position in the sequence was measured. Data were analysed using SPSS 23.0.

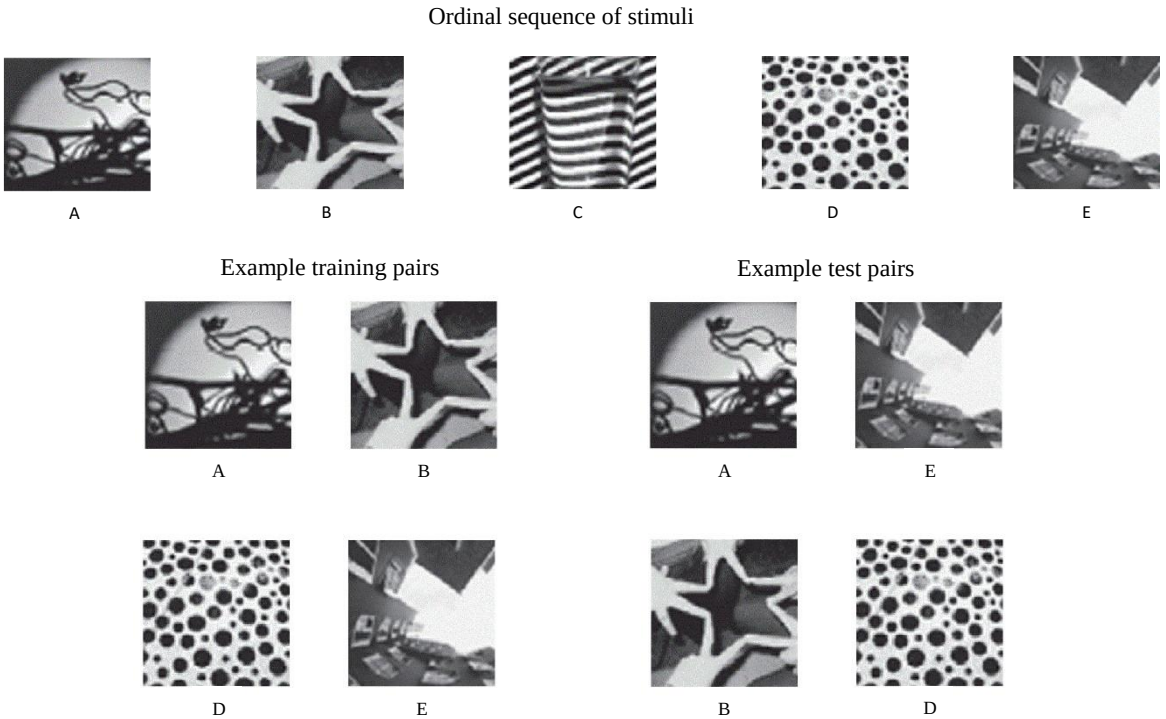

Figure 4.1. Examples of stimuli, and training and test pairs. A-E indicates hierarchical sequence. Positive reinforcement was given for choosing the higher-ranking of the pair.

4.4.3. Procedure

Participants were tested individually, as part of the normal school day, in a quiet room away from their usual classroom. Participants sat in front of the computer screen and it was first confirmed that they were happy to begin the task. Participants were provided with simple instructions about the task, which did not give them any information about the presence of an ordinal sequence: "You'll see two pictures together - touching one of them will show you a smiley face and touching the other one will show a sad face, and you need to find the smiley".

On the first practice trial, the experimenter showed the participant how to register a choice of stimulus on the screen. This was done by touching one of the images on the screen itself. During the first practice trial, the experimenter purposefully touched the "incorrect" stimulus on the screen, and the negative feedback appeared on the screen. The next practice trial was then displayed, however this time the experimenter purposefully chose the "correct" stimulus of the pair. This procedure was carried out in order to observe that the participant fully understood the difference between positively and negatively reinforced stimuli. On the third practice trial, the participant was encouraged to make the choice themselves. If the participant correctly chose the reinforced stimulus, they were then encouraged to "find as many smileys as you can". If at this stage the participant did not fully understand the contingencies of the task, the main experiment did not begin and the testing session was terminated. This did not occur with any participants from either group.

When it had been confirmed that the participant was happy to continue, the main experiment began. Three training blocks were presented. The first training block consisted of adjacent pairs (A+B-, B+C-, C+D-, D+E-) presented sequentially for 8 trials each. The left/right position of the stimuli were counterbalanced so that the positively reinforced

stimulus appeared on the left side and the right side an equal number of times. A criterion of 75% for each pair was set. If this was attained on the first attempt, the next training block was started; if not, the same training block was presented again. The experiment allowed participants to attempt each training block a maximum of three times before it continued automatically to the next block. The second training block consisted of a slightly more mixed presentation: the first two pairs (A+B- & B+C-) were presented in a random order for 16 trials, and then the next two pairs (C+D- & D+E-) were presented in a random order for 16 trials. The criterion was again set at 75% for each pair, with the block repeated twice more if this was not attained. For the third training block, all four pairs of stimuli were presented in a random order; again, the criterion was set at 75%, and the block repeated twice more if this was not attained.

After the training phase was completed, the test phase began directly after it; this consisted of a total of 20 trials. During this block, each previously seen pair of stimuli ("Adjacent") was presented for 2 trials. Participants were also presented with 12 trials of previously unseen pairs of stimuli. These were made up of previously trained individual stimuli, which were re-paired to create "Non-adjacent" or "transitive" stimuli (A+C-, A+D-, A+E-, B+D-, B+E-, C+E-).

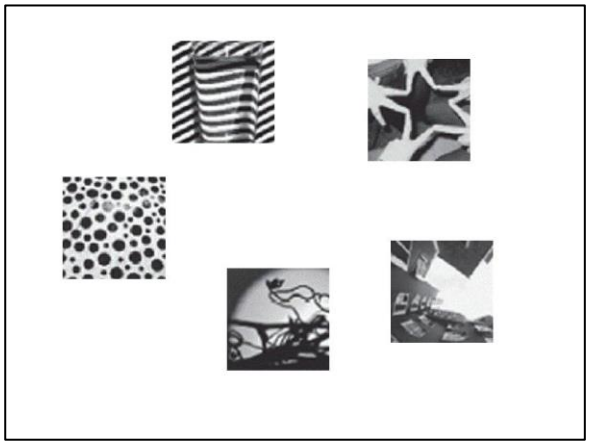

Figure 4.2. Presentation of stimuli during ordinal sequence task: Experiment 3.

On-screen feedback during the test phase was given in the same way as the training phase. Participants were also given verbal encouragement throughout the task. After the main task, the test of awareness of the ordinal sequence was presented. All the pictures were shown together on the screen (Fig 4.2), and participants were asked to "put them in order", by touching each picture on the screen, from A to E. Touching a picture would make it disappear from the screen. Participants did this until no pictures were left on-screen.

4.5. Results

4.5.1. Training blocks

4.5.1.1. Accuracy

Mean accuracy scores were compared across the three training blocks. The data are displayed in Table 4.2. A 2 (Group) x 3 (Block) mixed repeated measures ANOVA was used. Mauchly's test indicated that the assumption of sphericity had been violated ($X^2(2) = 9.58$, $p = .008$), therefore degrees of freedom were corrected using Greenhouse-Geisser estimates of sphericity ($\varepsilon = .84$). No significant interaction was found between Block x Group: $F(1.68, 79.12) = 0.64$, $p = .504$, $\eta_p^2 = .01$. However, there was a significant main effect of Group: $F(1, 47) = 5.55$, $p = .023$, $\eta_p^2 = .11$. There was also a significant main effect of Block: $F(1.68, 79.12) = 30.78$, $p < .001$, $\eta_p^2 = .40$.

Table 4.2. Accuracy scores for training phase: Experiment 3 (Means and Standard Deviations)

Block	TD (n = 24)	ASD (n = 25)	Cohen's d
1	.95 (.04)	.89 (.10)	0.79
2	.83 (.14)	.73 (.16)	0.67
3	.78 (.19)	.73 (.18)	0.27

Note. TD = Typically developing; ASD = Autism spectrum disorder.

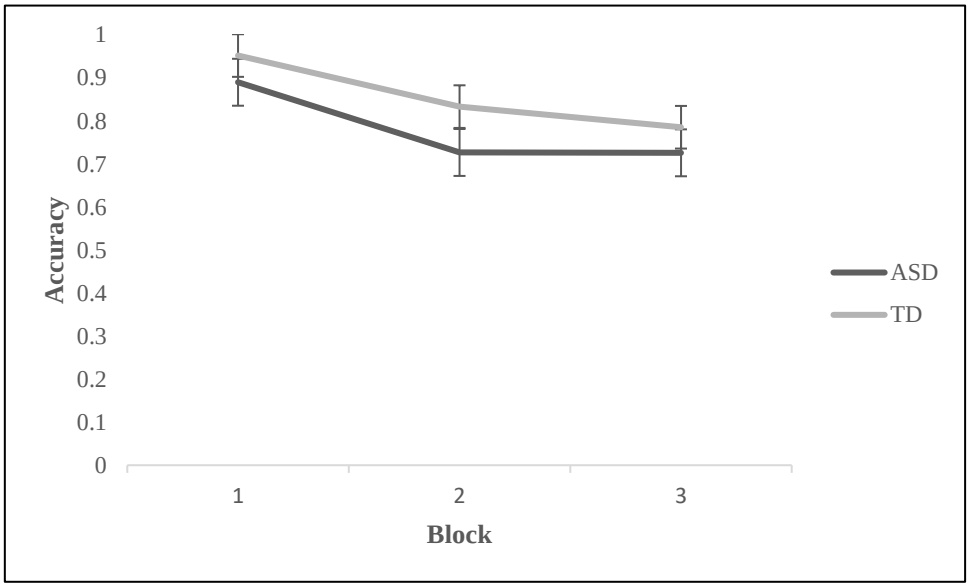

Figure 4.3. Accuracy (*M* ± SEM) for training blocks: Experiment 3.
TD = Typically developing; ASD = Autism spectrum disorder.

4.5.1.2. Accuracy compared to chance

Additional tests were carried out to determine whether performance was significantly above chance across the training blocks. A one-sample t-test was carried out, with the chance level set at 0.5. Participants in the TD group performed significantly above chance in all training blocks (Block 1: $t(23) = 54.53$, $p < .001$, $d = 11.13$; Block 2: $t(23) = 11.88$, $p < .001$, $d = 2.43$; Block 3: $t(23) = 7.3$, $p < .001$, $d = 1.49$). Participants in the ASD group also performed significantly above chance across all the blocks (Block 1: $t(24) = 19.46$, $p < .001$, $d = 3.89$; Block 2: $t(24) = 7.0$, $p < .001$, $d = 1.4$; Block 3: $t(24) = 6.2$, $p < .001$, $d = 1.24$).

4.5.1.3. Reaction time

Mean reaction times for correct trials were compared across the three training blocks; the data are displayed in Table 4.3. A 2 (Group) x 3 (Block) mixed repeated measures ANOVA was used. Mauchly's test indicated that the assumption of sphericity had been violated ($X^2(2) = 18.78$, $p < .001$), therefore degrees of freedom were corrected using

Greenhouse-Geisser estimates of sphericity (ε = .75). A significant interaction was found between Block x Group: $F(1.5, 70.4) = 4.68$, $p = .020$, $\eta_p^2 = .09$. There was also a significant main effect of Group: $F(1, 47) = 12.29$, $p = .001$, $\eta_p^2 = .21$, and a significant main effect of Block: $F(1.5, 70.4) = 17.3$, $p < .001$, $\eta_p^2 = .27$. Due to the interaction found, post-hoc tests were carried out. Independent t-tests were used to compare the reaction times for each training block. There was no significant difference in reaction time for the first training block: $t(47) = 1.77$, $p = .082$, $d = 0.51$. There was a significant difference in reaction time for the last two training blocks: Block 2: $t(47) = 3.46$, $p = .001$, $d = 0.99$; Block 3: : $t(47) = 3.13$, $p = .003$, $d = 0.89$.

Table 4.3. Reaction times for correct trials of training phase: Experiment 3 (Means and Standard Deviations)

Block	TD (*n* = 24)	ASD (*n* = 25)	Cohen's *d*
1	1811.7 (313.03)	1595.64 (510.37)	0.51
2	2401.75 (664.66)	1779.47 (594.39)	0.99
3	2723.36 (1082.3)	1884.07 (776.28)	0.89

Note. TD = Typically developing; ASD = Autism spectrum disorder. Reaction time (ms).

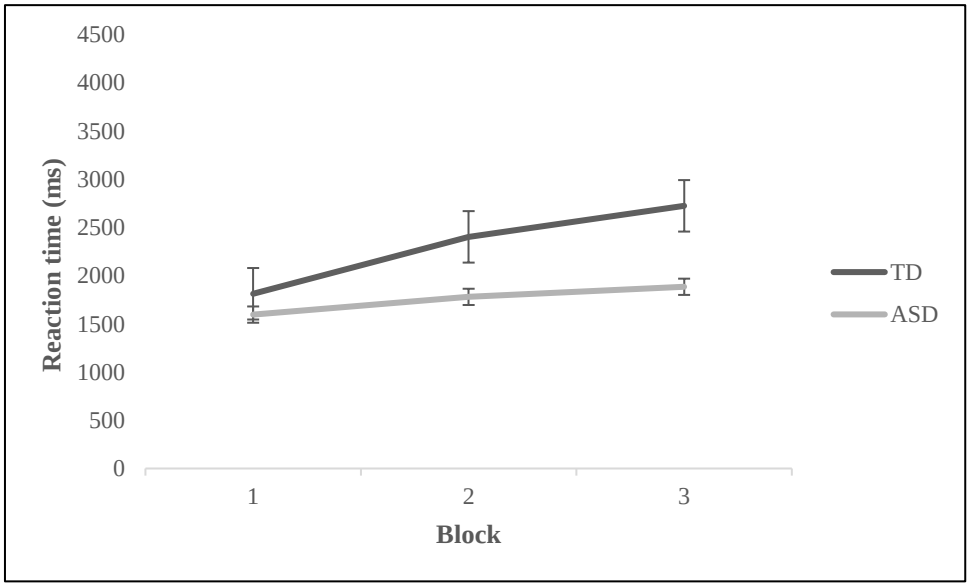

Figure 4.4. Reaction times (*M* ± SEM) for correct trials: training blocks of Experiment 3. TD = Typically developing; ASD = Autism spectrum disorder.

4.5.1.4. Number of attempts

The mean number of attempts were compared across the three training blocks. The data are displayed in Table 4.4. A 2 (Group) x 3 (Block) mixed repeated measures ANOVA was used. Mauchly's test indicated that the assumption of sphericity had been violated ($X^2(2) = 46.88$, $p < .001$), therefore degrees of freedom were corrected using Greenhouse-Geisser estimates of sphericity ($\varepsilon = .61$). No significant interaction was found between Block x Group: $F(1.22, 57.35) = 0.36$, $p = .591$, $\eta_p^2 = .01$, and there was no main effect of Group: $F(1, 47) = 1.06$, $p = .307$, $\eta_p^2 = .02$. However, there was a significant main effect of Block: $F(1.22, 57.35) = 54.65$, $p < .001$, $\eta_p^2 = .54$.

Table 4.4. Number of attempts per training block: Experiment 3 (Means and Standard Deviations)

Block	TD (*n* = 24)	ASD (*n* = 25)	Cohen's *d*
1	1.02 (.07)	1.09 (.19)	0.49
2	1.40 (.36)	1.62 (.39)	0.59
3	2.08 (.97)	2.16 (.90)	0.09

Note. TD = Typically developing; ASD = Autism spectrum disorder.

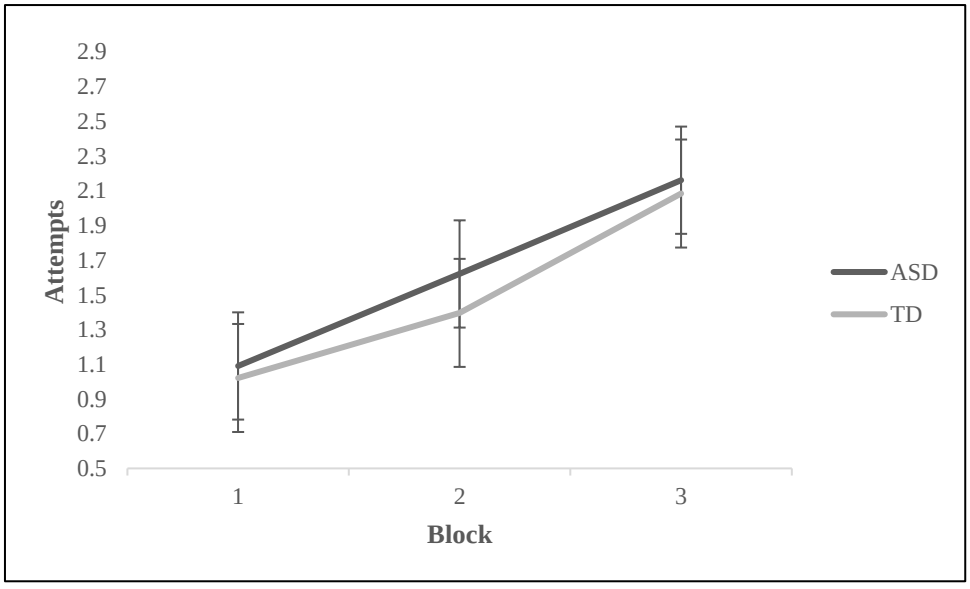

Figure 4.5. Number of attempts ($M \pm$ SEM) for each training block of Experiment 3. TD = Typically developing; ASD = Autism spectrum disorder.

4.5.2. Training pairs

4.5.2.1. Accuracy

Mean accuracy scores were compared for the four training pairs. The data are displayed in Table 4.5. A 2 (Group) x 3 (Pair) mixed repeated measures ANOVA was used. No significant interaction was found between Block x Pair: $F(3, 141) = 0.30$, $p = .817$, $\eta_p^2 = .01$. As previously reported, there was a significant main effect of Group: $F(1, 47) = 5.55$, $p = .023$, $\eta_p^2 = .11$. There was also a significant main effect of Pair: $F(3, 141) = 16.00$, $p < .001$, $\eta_p^2 = .25$.

Table 4.5. Accuracy scores for training pairs: Experiment 3 (Means and Standard Deviations)

Pair	TD (n = 24)	ASD (n = 25)	Cohen's d
AB	.89 (.09)	.82 (.15)	0.57
BC	.82 (.14)	.77 (.12)	0.38
CD	.80 (.17)	.71 (.15)	0.56
DE	.91 (.13)	.83 (.16)	0.55

Note. TD = Typically developing; ASD = Autism spectrum disorder.

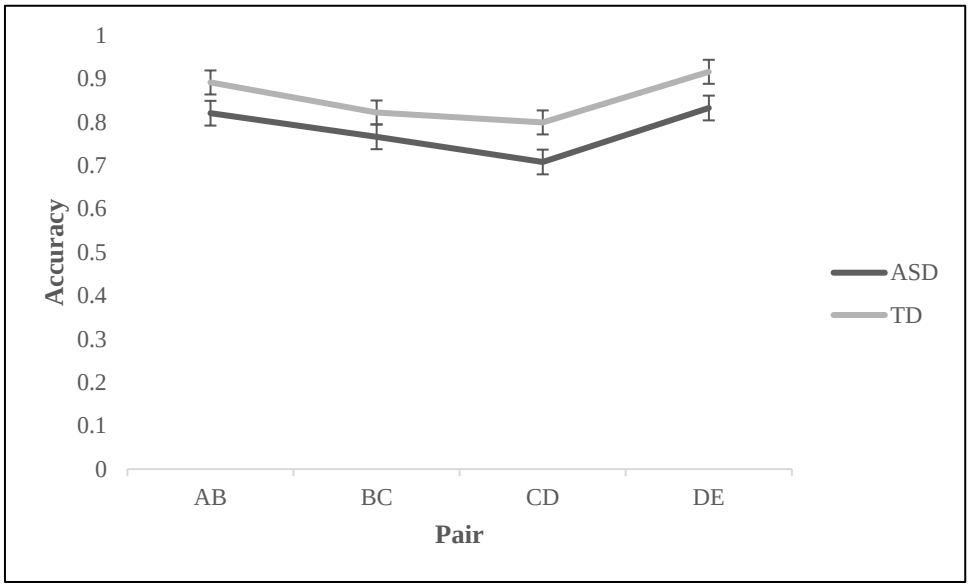

Figure 4.6. Accuracy (M ± SEM) for training pairs: Experiment 3.
TD = Typically developing; ASD = Autism spectrum disorder.

4.5.2.2. Reaction time

Mean reaction times for correct trials were compared for the four training pairs; the data are displayed in Table 4.6. A 2 (Group) x 4 (Pair) mixed repeated measures ANOVA was used. Mauchly's test indicated that the assumption of sphericity had been violated ($X^2(5) = 23.57$, $p < .001$), therefore degrees of freedom were corrected using Greenhouse-Geisser estimates of sphericity ($\varepsilon = .81$). No significant interaction was found between Pair x Group: $F(2.42, 113.8) = 2.89$, $p = .050$, $\eta_p^2 = .06$. There was a significant main effect of Group: $F(1, 47) = 12.29$, $p = .001$, $\eta_p^2 = .21$, and a significant main effect of Pair: $F(2.42, 113.8) = 9.81$, $p < .001$, $\eta_p^2 = .17$.

Table 4.6. Reaction times for correct trials of training pairs: Experiment 3 (Means and Standard Deviations)

Block	TD (*n* = 24)	ASD (*n* = 25)	Cohen's *d*
AB	2017.65 (404.29)	1785.07 (604.08)	0.45
BC	2670.59 (1062.43)	1888.48 (636.2)	0.89
CD	2485.73 (864.81)	1809.41 (850.2)	0.79
DE	2075.12 (459.85)	1529.27 (449.77)	1.20

Note. TD = Typically developing; ASD = Autism spectrum disorder. Reaction time (ms).

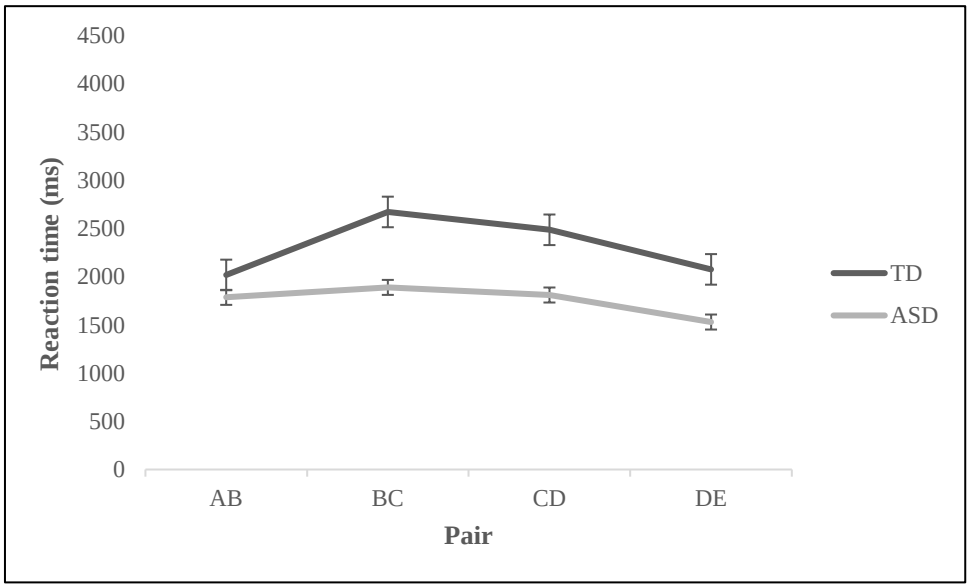

Figure 4.7. Reaction times ($M \pm$ SEM) for correct trials of training pairs: Experiment 3. TD = Typically developing; ASD = Autism spectrum disorder.

4.5.3. Test phase

4.5.3.1. Accuracy

The effect of trial type and test pair on mean accuracy scores was first examined. Due to the existence of unequal numbers of pairs for each trial type (i.e. four adjacent and six transitive pairs), the normal SPSS repeated measures procedure could not be used. Here the suggestion of IBM Support 'How to specify an ANOVA model in SPSS with nested repeated measures factors' (http://www-01.ibm.com/support/docview.wss?uid=swg21480571) was used, which yielded a significant three-way interaction: $F(1, 470) = 2.41$, $p = .001$, $\eta_p^2 = .09$. Subsequent analyses of two-way interactions and main effects were carried out using standard methods.

4.5.3.2. Trial type: Accuracy

Mean accuracy scores were compared for the two trial types, Adjacent and Transitive. The data are displayed in Table 4.7. A 2 (Group) x 2 (Trial Type) mixed repeated measures ANOVA was used. No significant interaction was found between Trial Type x Group: $F(1, 47) = 0.01$, $p = .921$, $\eta_p^2 < .01$, and there was no significant effect of Trial Type: $F(1, 47) = 0.72$, $p = .401$, $\eta_p^2 = .02$. However, there was a significant effect of Group: $F(1, 47) = 4.78$, $p = .034$, $\eta_p^2 = .10$.

Table 4.7. Accuracy scores for test phase: Experiment 3 (Means and Standard Deviations)

	TD (n = 24)	ASD (n = 25)	Cohen's d
Adjacent	.77 (.17)	.66 (.24)	0.53
Transitive	.80 (.18)	.68 (.22)	0.60

Note. TD = Typically developing; ASD = Autism spectrum disorder.

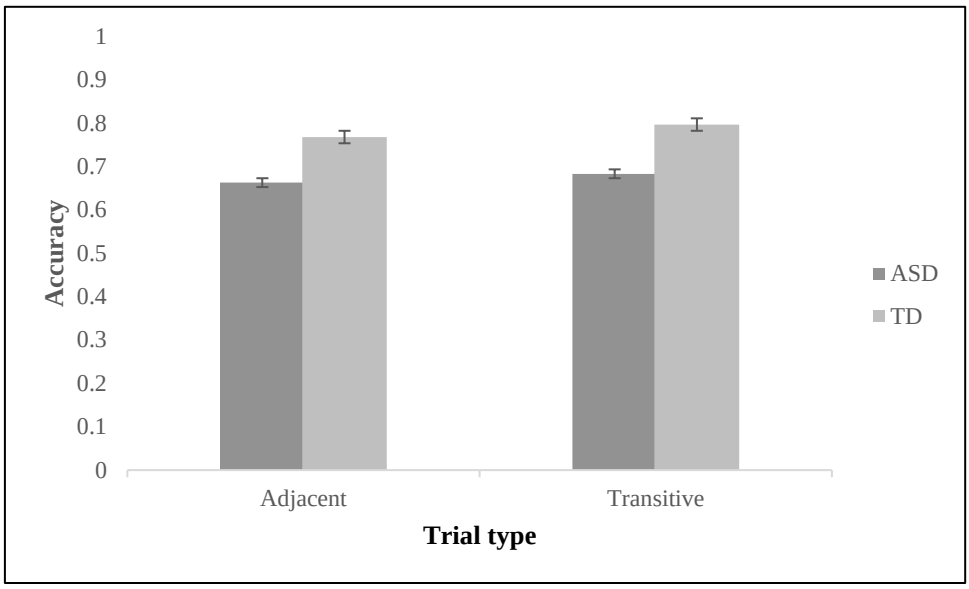

Figure 4.8. Accuracy (*M* ± SEM) for test phase: Experiment 3.
TD = Typically developing; ASD = Autism spectrum disorder.

4.5.3.3. Trial type: Accuracy compared to chance

Additional tests were carried out to determine whether the performance was significantly above chance for both groups for the two trial types. A one-sample t-test was used, with the chance level set at 0.5. Participants in the TD group performed significantly above chance for both trial types (Adjacent: $t(23) = 7.47$, $p < .001$, $d = 1.53$; Transitive: $t(23) = 8.08$, $p < .001$, $d = 1.65$). Participants in the ASD group also performed significantly above chance for both trial types (Adjacent: $t(24) = 3.29$, $p = .003$, $d = 0.66$; Transitive: $t(24) = 4.26$, $p < .001$, $d = 0.85$).

4.5.3.4. Test pairs: Accuracy

Mean accuracy scores were compared for the test pairs. The data are displayed in Table 4.8. A 2 (Group) x 10 (Pair) mixed repeated measures ANOVA was used. Mauchly's test indicated that the assumption of sphericity had been violated ($X^2(44) = 63.95$, $p = .027$), therefore degrees of freedom were corrected using Greenhouse-Geisser estimates of

sphericity (ε = .76). No significant interaction was found between Pair x Group: $F(6.84, 321.65) = 0.52$, $p = .817$, $\eta_p^2 = .01$. There was a significant main effect of Group: $F(1, 47) = 4.85$, $p = .033$, $\eta_p^2 = .09$, and a significant main effect of Pair: $F(6.84, 321.65) = 4.01$, $p < .001$, $\eta_p^2 = .08$.

Table 4.8. Accuracy scores for test pairs: Experiment 3 (Means and Standard Deviations)

Pair	TD (*n* = 24)	ASD (*n* = 25)	Cohen's *d*
AB	.90 (.25)	.72 (.38)	0.56
BC	.67 (.41)	.62 (.39)	0.12
CD	.63 (.42)	.60 (.41)	0.07
DE	.88 (.30)	.70 (.41)	0.50
AC	.73 (.42)	.68 (.32)	0.13
AD	.73 (.33)	.62 (.39)	0.30
AE	.88 (.22)	.82 (.32)	0.23
BD	.65 (.43)	.56 (.30)	0.24
BE	.90 (.25)	.72 (.29)	0.66
CE	.90 (.21)	.70 (.38)	0.65

Note. TD = Typically developing; ASD = Autism spectrum disorder.

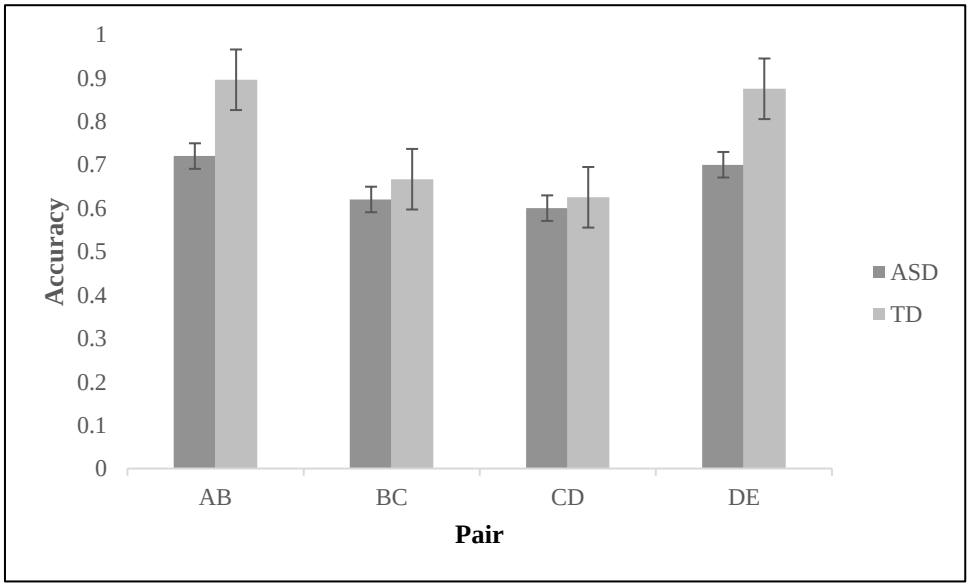

Figure 4.9. Accuracy (*M* ± SEM) for adjacent pairs of test phase: Experiment 3.
TD = Typically developing; ASD = Autism spectrum disorder.

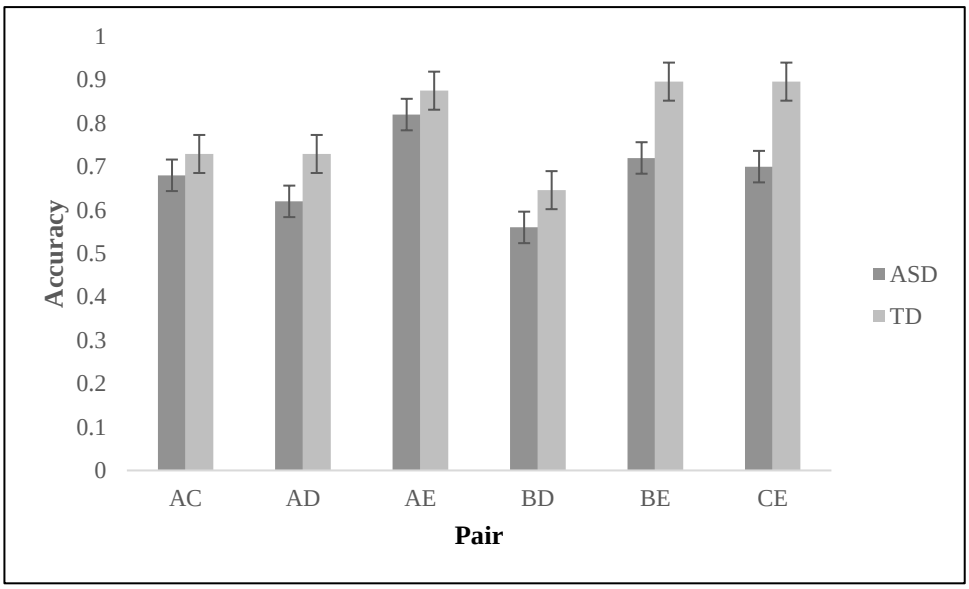

Figure 4.10. Accuracy (*M* ± SEM) for transitive trials of test phase: Experiment 3. TD = Typically developing; ASD = Autism spectrum disorder.

4.5.3.5. Test pairs: Accuracy compared to chance

Additional tests were carried out to determine whether performance for the test pairs was significantly above chance for both groups. A one-sample t-test was used, with the chance level set at 0.5. Participants in the TD group performed significantly above chance for the adjacent AB and DE pairs (AB: $t(23) = 7.62$, $p < .001$, $d = 1.56$; DE: $t(23) = 6.04$, $p < .001$, $d = 1.23$), but performed at chance level for BC and CD pairs (BC: $t(23) = 2.00$, $p = .057$, $d = 0.41$; CD: $t(23) = 1.45$, $p = .162$, $d = 0.30$). Participants in the ASD group also performed significantly above chance for the adjacent AB and DE pairs (AB: $t(24) = 2.86$, $p = .009$, $d = 0.57$; DE: $t(24) = 2.45$, $p = .022$, $d = 0.49$), but performed at chance level for BC and CD pairs (BC: $t(24) = 1.54$, $p = .136$, $d = 0.31$; CD: $t(24) = 1.23$, $p = .233$, $d = 0.24$).

Participants in the TD group performed significantly above chance for all transitive pairs other than the BD pair (AC: $t(23) = 2.70$, $p = .013$, $d = 0.55$; AD: $t(23) = 3.41$, $p = .002$, $d = 0.70$; AE: $t(23) = 8.31$, $p < .001$, $d = 1.70$; BD: $t(23) = 1.66$, $p = .110$, $d = 0.34$; BE: $t(23)$

= 7.62, $p < .001$, $d = 1.56$; CE: $t(23) = 9.35$, $p < .001$, $d = 1.91$). Participants in the ASD group performed significantly above chance for all transitive pairs other than the AD and BD pairs (AC: $t(24) = 2.82$, $p = .009$, $d = 0.56$; AD: $t(24) = 1.54$, $p = .136$, $d = 0.31$; AE: $t(24) = 5.02$, $p < .001$, $d = 1.00$; BD: $t(24) = 1.00$, $p = .327$, $d = 0.20$; BE: $t(24) = 3.77$, $p = .001$, $d = 0.75$; CE: $t(24) = 2.62$, $p = .015$, $d = 0.52$).

4.5.3.6. AE pair compared to BD pair

The outer transitive pair, A+E-, was compared to the inner pair, B+D-. A 2 (Group) x 2 (Pair) mixed repeated measures ANOVA was used. No significant interaction was found between Pair x Group: $F(1, 47) = 0.06$, $p = .801$, $\eta_p^2 < .01$. There was no significant main effect of Group: $F(1, 47) = 1.00$, $p = .322$, $\eta_p^2 = .02$. However, there was a significant effect of Pair: $F(1, 47) = 16.11$, $p < .001$, $\eta_p^2 = .26$.

4.5.3.7. BD pair

Accuracy for the two groups on the middle B+D- pair was compared using an independent t-test. There was no significant difference found between the groups: $t(47) = 0.81$, $p = .420$, $d = 0.23$.

4.5.3.8. Reaction time

The effect of trial type and test pair on mean reaction time scores for correct trials was examined. The data are displayed in Table 4.9. Due to the existence of unequal numbers of pairs for each trial type (i.e. four adjacent and six transitive pairs), the normal SPSS repeated measures procedure could not be used. As with the analysis of accuracy data, the suggestion of IBM Support 'How to specify an ANOVA model in SPSS with nested repeated measures factors' (http://www-01.ibm.com/support/docview.wss?uid=swg21480571) was used, which

yielded no significant three-way interaction: $F(1, 470) = 1.38$, $p = .129$, $\eta_p^2 = .05$; therefore no subsequent analyses were carried out.

Table 4.9. Reaction times for correct adjacent trials: Experiment 3 (Means and Standard Deviations)

Pair	TD (n = 24)	ASD (n = 25)	Cohen's d
AB	2543.04 (2590.07)	1991.3 (1898.66)	0.24
BC	2816.77 (1572.17)	2348.54 (2259.94)	0.24
CD	2824.69 (2086.11)	2905.0 (3203.49)	0.03
DE	3016.38 (1712.45)	1837.5 (1165.31)	0.80
AC	2933.81 (1784.18)	2211.88 (2867.43)	0.30
AD	2533.25 (2091.98)	2200.18 (1549.46)	0.18
AE	2409.23 (1920.59)	1633.76 (1278.87)	0.48
BD	3316.33 (2254.9)	2069.42 (1379.97)	0.67
BE	2700.38 (1737.94)	1557.32 (684.4)	0.87
CE	3259.44 (1702.59)	2902.82 (4423.72)	0.11

Note. TD = Typically developing; ASD = Autism spectrum disorder. Reaction time (ms).

4.5.4. Awareness of ordinal sequence

4.5.4.1. Accuracy

Mean accuracy scores were compared for distance of stimuli from actual position in the ordinal sequence. The data are displayed in Table 4.10. A 2 (Group) x 5 (Position) mixed repeated measures ANOVA was used. Mauchly's test indicated that the assumption of sphericity had been violated ($X^2(9) = 26.78$, $p = .002$), therefore degrees of freedom were corrected using Greenhouse-Geisser estimates of sphericity ($\varepsilon = .81$). No significant interaction was found between Position x Group: $F(3.23, 151.86) = 2.00$, $p = .111$, $\eta_p^2 = .04$. However, there was a significant effect of Position: $F(3.23, 151.86) = 3.51$, $p = .014$, $\eta_p^2 = .07$, and also a significant effect of Group: $F(1, 47) = 11.16$, $p = .002$, $\eta_p^2 = .19$.

Table 4.10. Awareness of ordinal sequence: Experiment 3 (Means and Standard Deviations)

	TD (*n* = 24)	ASD (*n* = 25)	Cohen's *d*
A	0.67 (1.17)	2.00 (1.56)	0.96
B	0.88 (1.00)	1.44 (1.16)	0.52
C	0.54 (0.66)	0.88 (0.83)	0.45
D	1.04 (1.08)	1.52 (0.96)	0.47
E	0.58 (1.18)	1.32 (1.35)	0.58

Note. TD = Typically developing; ASD = Autism spectrum disorder.
Distance from actual position in ordinal sequence.

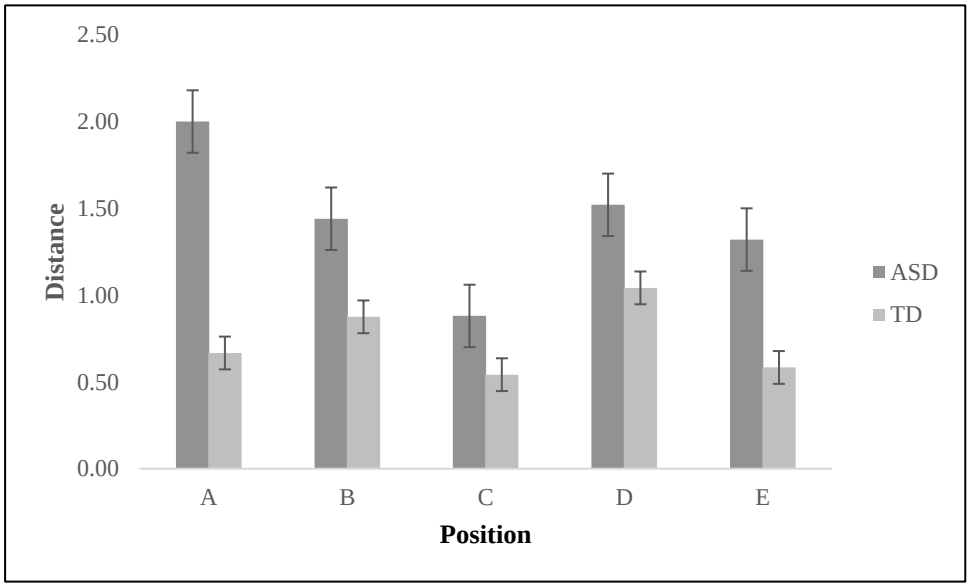

Figure 4.11. Accuracy (*M* ± SEM) for ordinal sequence task: Experiment 3. TD = Typically developing; ASD = Autism spectrum disorder. Distance = distance from actual position in the sequence. Position = actual position in the sequence.

4.5.5. Correlations

Correlational data are presented in Table 4.11. Analysis of each group separately revealed no correlations. Analysis of both groups together revealed no correlations between age at test and performance for the adjacent or transitive pairs. However, a significant positive correlation was found between age at test and performance for the ordinal sequence task, with older participants tending to score more highly (indicating poorer performance).

No correlations were found between either severity of autism symptoms, or non-verbal ability, and performance on adjacent or transitive pairs, or the ordinal sequence task. Verbal ability was also not correlated with performance on the adjacent or transitive pairs but was found to be significantly negatively correlated with performance on the ordinal sequence task; participants with higher scores on the BVPS-III obtained lower scores on the ordinal sequence task (indicating more accurate performance).

Table 4.11. Correlations between psychometric data and test phase (adjacent and transitive trials): Experiment 3

	TD			ASD			Both		
	Adj	Trans	Dist	Adj	Trans	Dist	Adj	Trans	Dist
Age (months)	-.02	.13	-.14	.21	.36	-.31	-.18	-.15	.32*
SRS	.03	-.06	-.07	.06	.42	-.29	-.14	-.11	.26
NVA	.08	.03	-.30	-.12	-.05	.07	.01	.04	-.19
VA	.12	-.18	-.33	.06	-.04	-.03	.21	.10	-.39**

Note. TD = Typically developing; ASD = Autism spectrum disorder; Both = TD and ASD groups together; SRS = Social Responsiveness Scale (raw score); NVA = Non-verbal ability (Raven's Coloured Progressive Matrices, raw score); VA = Verbal ability (British Picture Vocabulary Scale-III, raw score); Adj = Adjacent trials; Trans = Transitive trials; Dist = Distance from actual position. ** significant at $p < .01$; * significant at $p < .05$.

4.6. Discussion

Experiment 3 adapted a test of relational memory, the transitive inference task, in order to test relational memory in children with ASD and reduced language. Participants were presented with pairs of stimuli in sequential order and were required to choose the "higher-ranked" of the two; this stimulus of the pair was positively reinforced on-screen. Four adjacent pairs of stimuli were presented during the training phase. After training was completed, participants were presented with a test phase in which the previously seen adjacent stimuli were re-paired to create new, non-adjacent pairs which required inference from the adjacent pairs about the relations between them to solve. Participants were required

to use knowledge gained during the training phase about which stimulus of an adjacent pair was positively reinforced.

Accuracy for the training blocks was compared, which found that while the TD group was significantly more accurate overall, both groups became significantly less accurate across the blocks, indicating that both groups found the task more difficult as the trials became more randomly interspersed. However, it was still found that both groups performed significantly above chance across all the training blocks. Analysis of reaction time demonstrated that the TD group took significantly longer to respond overall than the ASD group, with this difference being more pronounced in the two final training blocks. It was also found that both groups' reaction time increased as the blocks went along. No significant differences were found between the groups in the number of attempts required to reach criterion at each block: both groups required significantly more attempts as the training blocks went on, reflecting the increasing difficulty of the training phase. Analysis of the individual training pairs was also carried out. Overall, the TD group was significantly more accurate at the training pairs, although it was shown that both groups were significantly less accurate for the middle pairs (BC and CD).

For the test phase, a significant three-way interaction between trial type, test pair, and group led to subsequent analyses. It was demonstrated that the TD group's performance was significantly more accurate overall than the ASD group, regardless of whether the stimuli were adjacent or transitive. However, a significant effect of test pair indicated that both groups found certain pairs more difficult than others. Analysis was therefore carried out to compare the performance on the test pairs to chance level. During the adjacent trials, it was found that both the TD group and the ASD group performed significantly above chance for pairs containing end stimuli (i.e. AB and DE), but performed at chance for the two inner pairs

(BC and CD). During the transitive trials, the TD group performed significantly above chance for all but the BD pair, whereas the ASD group performed significantly above chance for all but the AD and BD pairs. Performance of the groups on specific transitive pairs was also compared; performance for the "outer" pair (AE) was compared to that of the "inner" pair (BD). No overall group difference was found, but it was shown that both groups performed significantly more accurately for the "outer" pair.

The end task was included as a measure of whether participants had been aware of the overall ordinal sequence of the stimuli. All the pictures were presented, and participants were required to put them in order on the screen. The distance from the actual position in the sequence was compared between the groups; the TD group was found to be significantly more accurate overall, and it was also found that both groups were more accurate with the end stimuli.

When considering these findings alongside previous research, several interesting issues arise. Analysis of the training phase showed that although the performance of the TD group was significantly more accurate overall, the ASD group were still able to perform significantly above chance, indicating that they were able to learn the training pairs effectively. Despite this, both groups appeared to find the task more difficult as the training blocks continued. This was also reflected in the significantly increased reaction time and number of attempts required for both groups. The first training block presented the stimuli in sequential order, the second presented the stimuli in a slightly more random order, and the third training block presented all adjacent stimulus pairs in random order. This pattern of behaviour for both groups across the blocks may therefore indicate that they were not fully aware of the overall ordinal sequence before the trials were presented in random order. This

contrasts with the prediction that the TD group would be aware of the ordinal sequence, whereas the ASD group would be unaware.

This pattern of results was mirrored in the test phase; the performance of the TD group was significantly more accurate overall. This appears to partially fit with previous research from the animal literature, showing that more social animals perform significantly more accurately in transitive inference tasks (Maclean et al., 2008; Bond et al., 2010). Despite this, both groups performed well above chance overall for the adjacent and transitive trial types, which contrasts with previous research findings in which transitive inference was impaired in ASD (e.g. Silverman et al., 2013).

Further analysis of the individual pairs was indicative of the strategies each group may have been using to solve the task. During the training phase, it was found that both groups found the middle pairs (BC & CD) significantly more difficult. This would appear to suggest that both groups were using an associative strategy rather than encoding the entire ordinal sequence in memory; an associative strategy predicts a higher difficulty for middle pairs, due to the individual stimuli being reinforced and non-reinforced an equal number of times. This was also found in the test phase, in which performance on the extreme end pair (AE) was compared to that of the extreme inner pair (BD). Use of a flexible relational strategy predicts that there would be no difference in performance on these two pairs, as the entire stimulus sequence has been encoded, whereas use of an associative strategy predicts performance at chance for the inner pair. Both groups were significantly more accurate on the AE pair, and both performed at chance for the BD pair; therefore it can be inferred that both groups were using an associative strategy. This went against expectation for the typically-developing participants, who were predicted to use a flexible relational strategy. It also seems to fit with previous research that showed that awareness of relations between

object pairs was only adult-like at age ten (Townsend, Richmond, Vogel-Farley, & Thomas, 2010), although analysis of the end task given to participants demonstrated that the TD group were significantly more aware of the overall ordinal sequence.

The findings from the ASD group would appear to confirm the prediction that individuals with ASD and reduced language do use an associative strategy to solve a transitive inference task (e.g. Wynne et al., 1995). The findings also fit with previous research linking the activity of the hippocampus in individuals with ASD with transitive inference abilities (Solomon et al., 2015). These findings contrast with research from high-functioning adults with ASD, who were able to use a flexible relational strategy to solve the transitive inference task (Solomon et al., 2011). However, it suggests that language may be an important factor in strategy choice for this task. In the comparison of performance for the end task, in which participants were asked to rearrange the previously seen pictures in order, the ASD group were found to be significantly less accurate at reconstructing the overall order of the stimuli, which may suggest that although not adult-like in their transitive inference abilities, typically-developing children may use higher-order inferential reasoning to solve the task, and is consistent with the idea that language is important in the construction of relational strategies.

Chapter 5: Study 3: Visual paired comparison in Autism Spectrum Disorder

5.1. Introduction

The aim of this study was to employ a non-verbal method of measuring relational binding, in order to examine whether there are any differences between individuals with ASD and typical individuals in the way relational stimuli are visually explored. This was done with a preferential looking task, or visual paired comparison task, which simply involves measuring looking behaviour, without any directions to memorise information, or administration of an explicit recognition task. In this way it should be possible to investigate the relational memory of both individuals who are verbally-able, and those who are less so, thereby bringing together more coherently the findings of impairments in the domain of relational binding in those with ASD.

5.2. Visual paired comparison

Awareness of the way a pair of presented stimuli relate to each other can be investigated by testing visual novelty preference. In a typical example of this kind of task, a single object is presented, and then after a short delay that same object is presented again alongside a completely new object. If there is recognition of which stimulus is old and which is new, a novelty preference will be demonstrated, in which participants will look significantly longer at the new stimulus (Slater & Bremner, 2003, p.117). This awareness has been demonstrated in the earliest months of life; Fantz (1964) presented a pair of stimuli ten times in succession to typically-developing infants aged between two and four months old. Each trial consisted of one pattern that stayed constant across all the trials, and one pattern that was completely new for each trial. Corneal reflections were measured to determine which of the pair was being fixated on, and it was found that the infants fixated on the novel

pattern for significantly longer than the constant, thereby indicating recognition of a familiar stimulus and therefore longer exploration of a novel stimulus.

In a similar study, three-month old participants were shown a pair of stimuli, then one of the pair was shown on its own for a familiarisation period. After this the pair was shown again, and the looking time measured and compared to the looking time during the first presentation of the pair. The study found that the stimulus which was not used for the familiarisation period was looked at for longer. Although this study did not use a completely novel stimulus as one of the pair at the end of the familiarisation period, it does display a kind of novelty preference, in that the infants habituated to a single stimulus, and the less familiar stimulus elicited increased looking time when the pair were seen together again (Saayman, 1964). A novelty preference will usually be demonstrated regardless of whether the background on which the stimulus is presented stays the same or changes between familiarisation and test (Milewski & Siqueland, 1975) (although see Jones, Pascalis, Eacott, & Herbert, 2011).

The current study assessed the incidental encoding and retrieval of the arbitrary association between an item and the context in which it is presented. Performance on this kind of task has been shown to be adversely affected in a human participant with discrete hippocampal damage (Pascalis, Hunkin, Holdstock, Isaac, & Mayes, 2004). Pascalis, Hunkin, Bachevalier, and Mayes (2009) also investigated novelty preference in rhesus monkeys; the eye movements of a group of typically-developed monkeys were compared to those of hippocampally-damaged monkeys. When the background on which the stimuli were presented stayed the same between familiarisation and test, both groups showed a similar novelty preference. However, only the typically-developed monkeys showed a novelty preference when the background changed between familiarisation and recognition; the

hippocampally-damaged monkeys tended to look at each stimulus in the pair for approximately the same amount of time. This appeared to show that when these monkeys saw a familiar stimulus against a new background, it was perceived as a completely new stimulus. Within the same study, the task was also carried out with a human participant who had hippocampal damage, and the results were compared to those of a group of matched participants. The same pattern of results was found: the comparison group showed a significant novelty preference in both conditions, whereas the hippocampally-damaged participant showed a novelty preference *only* when the background stayed the same (Pascalis et al., 2009).

Eichenbaum, Yonelinas, and Ranganath (2007) assert that the hippocampus processes two sets of converging information from 1) the perirhinal and lateral entorhinal cortices, which process information about a stimulus, and 2) the parahippocampal and medial entorhinal cortices, which process information about the context in which the stimulus is presented. The hippocampus is responsible for encoding information about both sets of information. Pascalis et al.'s (2004) study appears to support this assertion. The perirhinal cortex, which was intact in both the hippocampally-damaged human and the monkeys, appeared to be sufficient to enable recognition in the same-context condition, where a fused, inflexible representation was adequate to enable recognition of a stimulus in the same context. However, since it does not allow for a *flexible* representation of the item and context, the perirhinal cortex was not able to support recognition of the item in the different-context condition. This appeared to indicate that participants with damaged hippocampi were processing the stimulus as a whole; the background and object appeared to constitute an inflexible, fused representation, which meant that when only the background was changed, the stimulus was viewed as completely novel, even though one element of it (the object) had been seen before. In contrast, typical individuals appear to process the object and

background flexibly and are able to represent the discrete parts of the stimulus together, as well as separately. As the hippocampally-damaged monkeys did not show this novelty preference when the background changed, the authors concluded that these findings upheld the idea that the hippocampus supports the formation of flexible rather than fixed object-background associations.

Following the procedure devised by Pascalis et al. (2009), Experiments 4 and 5 tested the existence of a flexible novelty preference in ASD by measuring eye movements. Photos of everyday objects were shown against different coloured or patterned backgrounds, and the background on which the objects were presented was manipulated to create two conditions: a same-context condition, where the background on which the pair of objects was presented was the same as the background on which the single object was presented, and a different-context condition, where the background on which the pair of objects was presented was different to the background on which the single object was presented.

Since individuals with ASD demonstrate memory patterns that are consistent with compromised hippocampal function, the prediction for the current study was that there would be no significant difference in novelty preference between the groups in the same-context condition, with both groups showing a novelty preference significantly above chance. Conversely, the prediction for the different-context condition was that typically-developing individuals would show a significant novelty preference, whereas individuals with ASD would show no significant novelty preference, with their looking times being approximately equal for each of the pair of items. In Experiment 4, a group of high-functioning adults with ASD and a matched group of typical individuals were tested. In Experiment 5, a group of school-aged children with ASD, and a group of typically-developing children were tested.

5.3. Experiment 4: Visual Paired Comparison in Adults

5.4. Method

5.4.1. Participants

A total of thirty-nine participants were recruited for the experiment. Twenty-one individuals (eighteen males and three females) with ASD, and eighteen typical individuals (fourteen males and four females) were tested. All individuals were recruited from the Autism Research Group's existing database of participants. The comparison group was matched to the ASD group to within two points of Full-Scale IQ, which was measured using the Weschler Adult Intelligence Scale (WAIS-R-UK or WAIS-III-UK). All participants in the ASD group had a clinical diagnosis according to the ICD-10 or DSM-IV-TR criteria for Asperger syndrome. Before testing commenced, approval was obtained from the ethics committee of City, University of London. Table 5.1 shows age and psychometric data for both groups. Independent t-tests were carried out using age and psychometric data from each group, which found no significant differences between the groups on any of the factors.

Table 5.1. Participant characteristics: Experiment 4 (Means and Standard Deviations)

	TD (n =18)	ASD (n =21)	t	p	Cohen's d
Age (years)	42.36 (13.58)	40.81 (11.78)	0.38	.705	0.12
Range	20-60	26-67			
VIQ	111.06 (16.97)	110.33 (15.68)	0.14	.891	0.04
Range	76-138	74-135			
PIQ	104.06 (17.77)	105.81 (17.33)	-0.31	.757	0.10
Range	73-136	74-132			
FIQ	108.94 (18.58)	109.38 (17.29)	-0.08	.940	0.02
Range	74-135	73-134			

Note. VIQ = Verbal IQ (Wechsler Adult Intelligence Scale - Revised (WAIS-R) or Wechsler Adult Intelligence Scale - 3rd UK ed. (WAIS-III^{UK}); PIQ = Performance IQ (WAIS-R or WAIS-III^{UK}); FIQ = Full-scale IQ (WAIS-R or WAIS-III^{UK}).

5.4.2. Materials and Design

Stimuli were created for the study using GIMP Image Manipulation software and were based on the method utilised by Pascalis et al. (2009): stimuli consisted of pairs of photos of everyday, easily recognisable objects, set against either a plain coloured or patterned background. All objects and backgrounds were novel on each trial. The pairs of objects were matched for size, brightness and complexity, and each object and background together measured approximately 10cm x 10cm (Figure 5.1). Items were presented using E-Prime software on a 15" Toshiba laptop computer screen, and participants' eye movements were measured via a head mounted ETL-500 "Iscan" eye tracker, which records stimulus fixation by measuring corneal reflection.

Data were analysed using a MATLAB program, and SPSS 23.0. The experiment used a 2 x 2 mixed repeated measures design, with a repeated measures variable of Context (Same x Different). In the same context condition the background on which the objects were displayed stayed the same between familiarisation and recognition, and in the different context condition the background changed between familiarisation and recognition. The between-subjects variable was Group (TD x ASD).

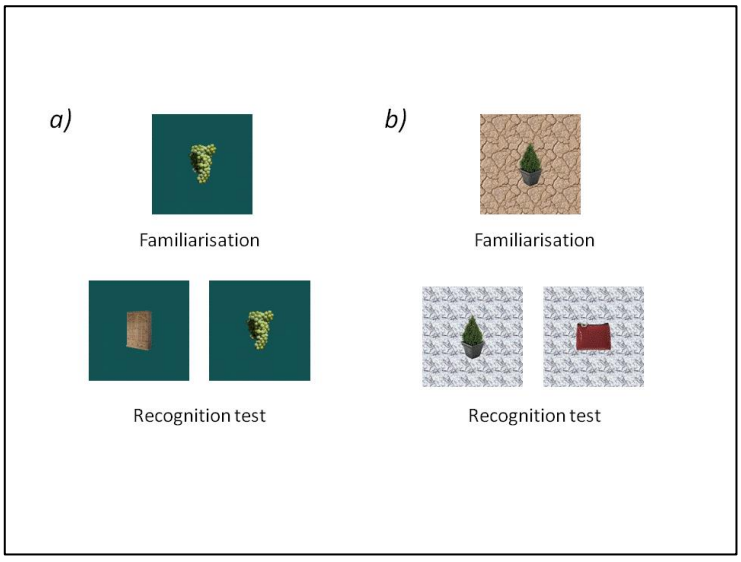

Figure 5.1. Presentation of stimuli: a) same context; b) different context

5.4.3. Procedure

Participants sat in front of a computer screen wearing the head-mounted eye tracker, which was calibrated to each participant's eye movements. A single object on either a coloured or patterned background was presented in the middle of a white screen for 5 seconds (the familiarisation phase) which was followed by a delay of 1 second in which a blank screen was displayed, after which a pair of objects were presented together on-screen for a further 5 seconds (the recognition phase). One of these objects had been displayed in the previous familiarisation phase. The length of intervals for the familiarisation and recognition phases was based on previous findings that these times were sufficient to elicit a novelty preference (Pascalis et al., 2004; 2009).

24 trials were presented in total, which comprised 12 trials of the same context condition, and 12 trials of the different context condition. Trials from the two conditions were mixed and presented in a random order. The position of the familiar stimulus on either the left or the right of the screen was counterbalanced across trials, in order to allow for any possible bias in general looking direction. Four versions of the experiment were created, which ensured that across participants each object had been seen as either the new or old object in the familiarisation phase, and also as either in the left or right position during the recognition phase. Matched participants saw the same version, and each version was used at least once.

An information sheet was given to each participant (Appendix 4), which included information about the experiment, and a consent form (Appendix 5). After informed consent was obtained, verbal instructions were given to participants that they would see a series of pictures, and that they should "look at the screen as if you were watching TV", as per the

instructions given by Pascalis et al. (2009). This was to try to ensure looking behaviour which was as naturalistic as possible under the circumstances.

5.5. Results

5.5.1. Total looking time during recognition phase

Mean total looking times were analysed using SPSS 23.0, and are set out in Table 5.2. For each condition, independent t-tests were carried out to determine whether there was a significant difference between groups in the total time spent exploring the stimuli during the recognition phase. Analysis of these data showed that the groups spent a similar amount of time exploring the stimuli in each condition: Same $t(37) = 1.19$, $p = .241$, $d = 0.38$; Different $t(37) = 1.53$, $p = .135$, $d = 0.49$.

Table 5.2. Total looking time during recognition phase: Experiment 4 (Means and Standard Deviations)

	TD (n = 18)	ASD (n =21)	Cohen's d
Total	3952.5 (489.1)	3731.9 (474.77)	0.46
Same	3938.33 (516.7)	3740.95 (515.05)	0.38
Different	3966.67 (534.75)	3722.86 (462.54)	0.49

Note. TD = Typically developing; ASD = Autism spectrum disorder; Same = Same context condition; Different = Different context condition. Looking time (ms).

5.5.2. Novelty preference

Data were analysed using SPSS 23.0, following the paradigm used by Pascalis et al. (2009), in which novelty preference was analysed. This was defined as the mean time spent looking at the novel stimulus as a proportion of the total looking time during the presentation of the pair of objects (recognition phase). The data are set out in Table 5.3. A 2 (Group) x 2 (Context) mixed repeated measures ANOVA was used. No significant interaction was found

between Group and Context: $F(1, 37) = 0.23$, $p = .634$, $\eta_p^2 = .01$. The main effect of Group was also found to be non-significant: $F(1, 37) = 0.05$, $p = .822$, $\eta_p^2 < .01$. However, a significant main effect of Context was found: $F(1, 37) = 4.88$, $p = .033$, $\eta_p^2 = .12$.

Table 5.3. Novelty preference: Experiment 4 (Means and Standard Deviations).

	TD (n = 18)	ASD (n =21)	Cohen's d
Same	.61 (.10)	.61 (.12)	0.0
Different	.58 (.11)	.57 (.12)	0.1

Note. TD = Typically developing; ASD = Autism spectrum disorder; Same = Same context condition; Different = Different context condition. Fixation time as a proportion of total looking time during recognition phase.

5.5.3. Novelty preference compared to chance

Additional tests were carried out to determine whether the novelty preferences exhibited were significantly above chance. A one-sample t-test was carried out, with the chance level set at 0.5. Participants in the TD group showed a novelty preference significantly above chance in both conditions: Same $t(17) = 4.52$, $p < .001$, $d = 1.07$; Different $t(17) = 3.25$, $p = .005$, $d = 0.77$. Participants in the ASD group also showed a

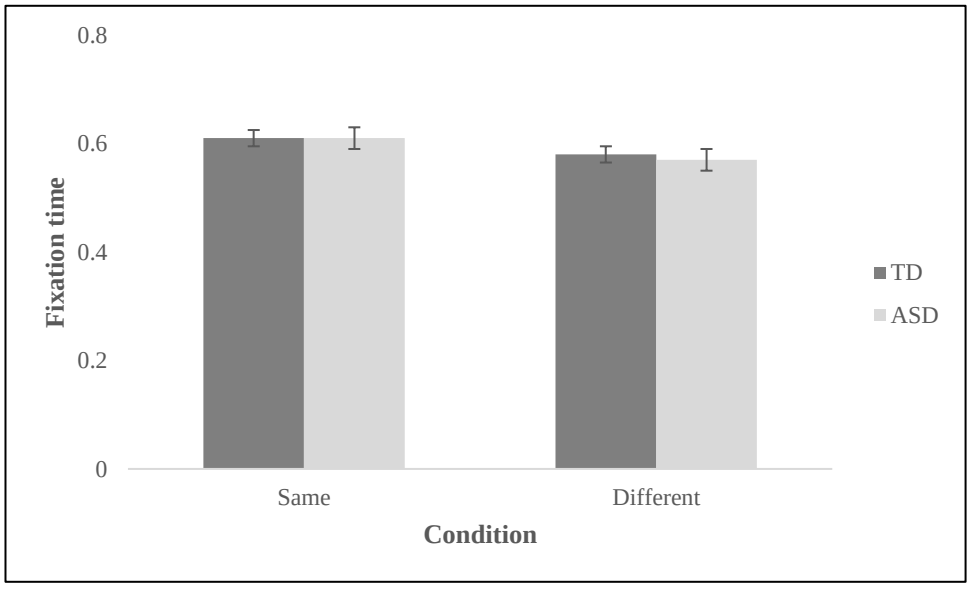

Figure 5.2. Fixation time ($M \pm$ SEM) for novel stimulus as a proportion of total looking time during recognition phase: Experiment 4. TD = Typically developing; ASD = Autism spectrum disorder.

novelty preference significantly above chance in both conditions: Same $t(20) = 4.14$, $p = .001$, $d = 0.9$; Different $t(20) = 2.60$, $p = .018$, $d = 0.57$.

5.6. Discussion: Experiment 4

Experiment 4 aimed to replicate with high-functioning adults with ASD a previous study carried out by Pascalis et al. (2009), which measured and compared the eye movements of hippocampally-damaged participants and typical participants, and found that when the context in which a stimulus is presented stays the same between familiarisation and test, both groups showed a comparable novelty preference, whereas when the context was changed between familiarisation and test, only the comparison group showed a novelty preference that was significantly higher than chance levels. The prediction for Experiment 4 was that, since individuals with ASD show similar memory impairments to individuals with comprised hippocampal function, they would also show no novelty preference when the background on which a stimulus is presented changes between familiarisation and test.

Total looking times were compared during the recognition phase for each group, and no significant differences were found between the groups in the total length of time spent exploring the paired stimuli. This means that any differential looking behaviour pertaining to novelty preference could not simply be attributed to one group having been exposed to the stimuli for longer.

Analysis of novelty preference showed no significant interaction between group and context, and no significant difference between the groups; both groups looked significantly longer at the novel stimulus when the background stayed the same, contrary to the expectation that the only TD group would show the same level of novelty preference in both conditions. In addition to these findings, it was demonstrated that the novelty preferences

exhibited by each group were significantly above chance in both conditions. This conflicted with the prediction that significant novelty preferences would be exhibited for all except the ASD group in the different context condition.

5.7. Experiment 5: Visual Paired Comparison in Children

5.8. Method

5.8.1. Participants

A total of forty-five school-aged children were recruited, comprising two groups. Twenty-one children (sixteen males and five females) aged between twelve and sixteen with an autism spectrum disorder were recruited from four special educational secondary schools in the London area. All participants in this group had a confirmed diagnosis of ASD, according to school records of each child's statement of special needs. Where possible, this diagnosis was supported by scores obtained from completion by teachers of the Social Responsiveness Scale (SRS, Constantino, 2005). Participants in this group also had reduced language, which was confirmed by scores obtained from completion by the researcher of the British Picture Vocabulary Scale: Third Edition (BPVS-III, Dunn, Dunn, & Styles, 2009).

To form the comparison group, twenty-four children (thirteen boys and eleven girls) aged between seven and eleven were recruited from two mainstream primary schools, also in the London area. As reported by the schools, none of these children had any developmental or learning difficulties, which was confirmed by completion by teachers of the SRS, and displayed verbal ability within the typical range for their age; this was confirmed by completion by the researcher of the BPVS-III for each child.

The study was approved by the City, University of London Ethics committee, and informed consent was obtained first from the headteacher of each participating school (Appendices 1 & 2), and then from each child's parent or carer (Appendix 3). Verbal assent was also obtained from each child before the testing session began.

Typically-developing participants (TD group) were matched on non-verbal ability to participants with ASD (ASD group), to within 2 points on Ravens Coloured Progressive Matrices (RCPM, Raven, 1958). Independent t-tests were carried out using age and psychometric data from each group, which found no significant difference between the groups on non-verbal ability. However, significant differences were found between the groups on age, severity of autism symptoms, and verbal ability. Table 5.4 shows age and psychometric data for both groups.

Table 5.4. Participant characteristics: Experiment 5 (Means and Standard Deviations)

	TD (n =24)	ASD (n =21)	t	p	Cohen's d
Age (months)	99.61 (16.21)	166.1 (14.63)	-14.36	< .001	4.31
Range	82-138	143-192			
SRS	17.63 (14.89)	82.07 (16.92)	-12.24	< .001	4.04
Range	0-62	47-111			
NVA	25.33 (4.82)	24.71 (4.8)	0.43	.669	0.13
Range	15-35	16-34			
Percentile	42.01 (28.18)	9.75 (18.6)			
VA	106.46 (15.46)	92.43 (20.31)	2.63	.012	0.78
Range	74-132	56-125			
Percentile	48.54 (27.89)	.65 (1.29)			

Note. SRS = Social Responsiveness Scale (raw score, cutoff = 70); NVA = Non-verbal ability (Raven's Coloured Progressive Matrices, raw score); VA = Verbal ability (British Picture Vocabulary Scale-III, raw score).

5.8.2. Materials and Design

The stimuli used were identical to those in Experiment 4. The items were presented using E-Prime software on a 15" Dell laptop computer screen, and participants' eye movements were measured via a screen-mounted Tobii X1 Light eye tracker, recording stimulus fixations via corneal reflection. There were several reasons for the decision to use this eye tracker rather than the head-mounted eye tracker previously used in Experiment 4. As testing was being carried out in the children's schools, a portable method of measuring eye movements was necessary. This method was also felt to be less intrusive for those children in the ASD group who displayed sensitivity to certain tactile stimuli. The conditions (Same x Different context) were identical to those of Experiment 4. Data were analysed using MATLAB, and SPSS 23.0.

5.8.3. Procedure

Participants were seated in front of the computer screen; the screen-mounted eye tracker was then calibrated to the individual's eye movements. The familiarisation and recognition phases were identical to those of Experiment 4 regarding length of intervals, number of trials, counterbalancing, and presentation to matched participants.

Participants were tested individually in a designated testing room in their school, as part of their regular school day. After verbal assent was obtained from the participant, verbal instructions were given (as per Experiment 4) that they would see some pictures, and that they should "look at the screen as if you were watching TV".

5.9. Results

5.9.1. Total looking time during recognition phase

Mean total looking times were analysed using SPSS 23.0, and are presented in Table 5.5. For each condition, independent t-tests were carried out to determine whether there was a significant difference between groups in the total time spent exploring the stimuli in the recognition phase. Analysis of these data showed that the groups spent a significantly different amount of time exploring the stimuli in each condition: Same $t(43) = 3.04$, $p = .004$, $d = 0.90$; Different $t(43) = 3.34$, $p = .002$, $d = 1.00$.

Table 5.5. Total looking time during recognition phase: Experiment 5 (Means and Standard Deviations)

	TD (n =24)	ASD (n =21)	Cohen's d
Total	2348.64 (737.02)	1613.58 (789.38)	0.96
Same	2304.58 (743.75)	1590.3 (833.09)	0.90
Different	2392.69 (746.32)	1636.87 (771.83)	1.00

Note. TD = Typically developing; ASD = Autism spectrum disorder; Same = Same context condition; Different = Different context condition. Looking time (ms).

5.9.2. Novelty preference

Data were analysed using SPSS 23.0, according to the paradigm used by Pascalis et al. (2009), in which novelty preference was measured. The data are displayed in Table 5.6. This was defined as the mean time spent looking at the novel stimulus as a proportion of the total looking time during the presentation of the pair of objects. A 2 (Group) x 2 (Context) mixed repeated measures ANOVA was used. No significant interaction was found between Group and Context: $F(1, 43) = 2.24$, $p = .142$, $\eta_p^2 = .05$. There was no significant main effect of Group: $F(1, 43) = 3.04$, $p = .088$, $\eta_p^2 = .07$; however there was a significant main effect of Context: $F(1, 43) = 11.59$, $p = .001$, $\eta_p^2 = .21$.

Table 5.6. Novelty preference: Experiment 5 (Means and Standard Deviations).

	TD (n =24)	ASD (n =21)	Cohen's d
Same	.58 (.09)	.64 (.08)	0.70
Different	.55 (.08)	.56 (.11)	0.10

Note. TD = Typically developing; ASD = Autism spectrum disorder; Same = Same context condition; Different = Different context condition. Fixation time as a proportion of total looking time during recognition phase.

5.9.3. Novelty preference compared to chance

Additional tests were carried out to determine whether the novelty preferences exhibited were significantly above chance. A one-sample t-test was carried out, with the chance level set at 0.5. Participants in the TD group showed a novelty preference significantly above chance in both conditions: Same $t(23) = 4.55$, $p < .001$, $d = 0.93$; Different $t(23) = 3.40$, $p = .002$, $d = 0.69$. Participants in the ASD group also showed a novelty preference significantly above chance in both conditions: Same $t(20) = 8.61$, $p < .001$, $d = 1.88$; Different $t(20) = 2.80$, $p = .011$, $d = 0.61$.

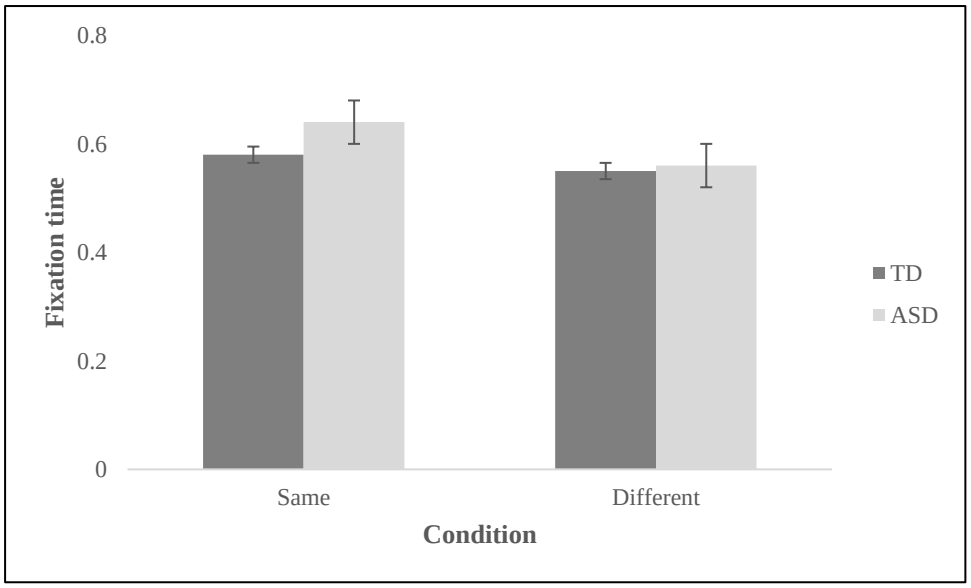

Figure 5.3. Fixation time ($M \pm$ SEM) for novel stimulus as a proportion of total looking time during recognition phase: Experiment 5. TD = Typically developing; ASD = Autism spectrum disorder.

5.10. Discussion

Experiment 5 aimed to replicate the previous study carried out with adults with ASD. Total looking times during the recognition phase for each group were first compared, and there was a significant difference found between the groups in the total length of time spent exploring the paired stimuli, with the TD group exploring the stimuli for a significantly longer time. This finding runs contrary to that of the previous study and has the potential to imply that differential looking behaviour pertaining to novelty preference can be attributed to one group having been exposed to the stimuli for longer. However, this should be negated by the fact that analysis of novelty preference was based on the proportion of the total time spent exploring the novel stimulus, rather than any absolute numbers based on the amount of time for which the stimuli were presented.

Analysis of novelty preference showed no significant interaction between group and context, and no significant main effect of group. However, there was a significant difference in the proportion of time spent looking at the novel stimulus dependent on the context, with both groups looking significantly longer at the novel stimulus when the background stayed the same. Again, this was contrary to the expectation that only the control group would show the same level of novelty preference in both conditions. However, these findings mirror those from Experiment 4, in which high-functioning adults with ASD also looked longer at the novel stimulus in the same context condition. In addition to this, again mirroring the results from the adults, it was demonstrated that the novelty preferences exhibited by each group were significantly above chance in both conditions.

5.11. Discussion of Experiments 4 and 5

Experiments 4 and 5 adapted a visual paired comparison task from a previous study that demonstrated that compromised hippocampal function leads to a difficulty in processing the context in which a stimulus is presented (Pascalis et al., 2009). Pictures of objects were shown against different backgrounds in two conditions: a same-context condition, in which the background on which the pair of objects was presented stayed the same between familiarisation and test, and a different-context condition, in which the background changed between familiarisation and test. Since individuals with ASD demonstrate memory patterns that are consistent with compromised hippocampal function, the prediction for the current study was that both typically-developing individuals and those with ASD would show a significant novelty preference in the same-context condition, whilst in the different-context condition only the typically developing individuals would show a significant novelty preference, whereas the looking times for individuals with ASD would be approximately equal for each of the pair of items.

Experiment 4 administered a visual paired comparison task to adults with ASD and compared them to typical adults matched on full-scale IQ. It was found that both groups looked longer at the novel stimulus when the background stayed the same between familiarisation, with no group differences found. It was also demonstrated that both groups showed a novelty preference significantly above chance in both the same- and different-context conditions. Experiment 5 administered the identical task to children with ASD and reduced language, and a group of typically-developing children, matched on non-verbal mental ability. The same pattern of results was partially found; no group difference in novelty preference was found, with both groups again looking significantly longer at the novel stimulus when the background stayed the same between familiarisation and test. A

group difference was found however, between the total time taken to explore the pair of stimuli during the test phase, showing that the typically-developing participants explored the stimuli for significantly longer. However, this difference would not account for any differential novelty preference, as the analysis was based on the proportion of the total looking time, rather than absolute numbers based on the length of presentation of the stimuli.

Experiment 4 and 5's findings on novelty preference deviate from the study on which they were based (Pascalis et al., 2009), and the reasons for this need to be carefully considered. Findings from both experiments parallel each other, showing that the task was successful in eliciting a significant novelty preference from both groups in both conditions, and thereby demonstrating the task to be an effective incidental and non-verbal measure of relational binding, and therefore hippocampal function.

It is possible, despite previous findings that individuals with ASD display memory impairments consistent with compromised hippocampal function, that they may be cognitively unrelated to individuals with hippocampal damage. These findings would therefore appear to shift the focus from the medial temporal lobe as the region responsible for ASD-related memory difficulties, and perhaps shift attention back towards possible dysfunction in the frontal lobes. Alternatively, it may be possible that in individuals with ASD, the functions of the hippocampus are selectively compromised, with some remaining intact.

Chapter 6: General Discussion

6.1. Aims of the research

The aim of the current research was to develop a set of non-verbal tasks that test relational memory, to examine the level of this ability in children with ASD and reduced language. It aimed to replicate the characteristic impairments in relational memory which were previously found in high-functioning individuals on the autism spectrum, in order to generalise these impairments to the autism spectrum as a whole.

The research aimed to achieve this objective by developing behavioural paradigms from the animal literature on relational memory, which necessarily measure this kind of memory non-verbally, and adapt them for use with individuals with ASD across the whole of the spectrum, regardless of linguistic ability. This aimed to provide paradigms which would be suitable for all participants with ASD and provide more rigorous tests of relational memory in ASD, independent of the level of functioning of the individual.

6.1.1. Experiments 1 and 2

Experiment 1 administered a test of configural memory, a biconditional discrimination task, to typically-developing participants, and participants with ASD and reduced language abilities. In this task, awareness of how the stimuli were configured was required for success. During the training phase, the TD group was found to be more accurate overall, although it was also found that the ASD group performed the discrimination significantly above chance levels, indicating that they were also able to learn the discrimination effectively. During the test phase of the biconditional discrimination task, the TD group was again found to be significantly more accurate overall, which contrasts with predictions. Despite this, it was still found that the ASD group performed well above chance

levels, indicating that they also had encoded the configuration of the stimuli sufficiently to able to solve the task. This finding aligns with the prediction that individuals with ASD would be able to solve a task of biconditional discrimination, and also fits with previous research from the animal literature, in which rats with hippocampal lesions were able to learn a biconditional discrimination (Sanderson et al, 2006; Aggleton et al., 2007).

Experiment 2 administered a structural discrimination task to participants; this task also requires an awareness of the configuration of stimuli but includes an additional spatial component: both stimuli have the same configuration of elements but are arranged differently spatially. To be able to choose the reinforced stimulus, there must be an awareness of the spatial arrangement. This kind of task is thought to be mediated by the hippocampus (Aggleton & Pearce, 2001), and led to the prediction for Experiment 2 that, as individuals with ASD show a similar patterning of memory impairments as those with compromised hippocampal function, they would also be impaired on this task.

The findings from Experiment 2 partly confirm this prediction. During the training phase, no group differences were found; both groups' performance became less accurate across the training blocks, and both groups' reaction time increased across the blocks. However, a difference was found when comparing both groups' performance to chance levels: the TD group performed the discrimination well above chance levels for all the training blocks, whereas the ASD group performed at chance for the final training block, suggesting that the ASD group were not able to learn the discrimination as readily. Similar results were found from analysis of the test phase. No overall group differences were found in either accuracy or reaction time, although planned comparisons highlighted a difference. For the familiar trials (stimuli pairs on which they had been previously trained), both groups performed significantly above chance. However, for the novel stimuli, (stimulus pairs from

the training phase which were re-paired to create new stimulus pairs), only the TD group performed significantly above chance. This appears to confirm the prediction that the ASD group would display a difficulty with the novel trials, and therefore with the spatial component of the task.

Throughout both experiments, participants were presented with a concurrent test of simple discrimination. This was done to control for any potential difference in discrimination of basic visual stimuli. No differences were found between the groups for either experiment in accuracy, performance above chance levels, or reaction time. This demonstrated that the ASD group were just as able as the TD group to discriminate between basic visual stimuli; therefore any differences in performance for experimental trials could not be accounted for by individual differences in basic visual discrimination.

These findings demonstrate this task to be an effective test of relational memory in ASD, and partially align with previous research from participants with hippocampal dysfunction, in which hippocampal lesions led to impairment in tasks which required awareness of the specific spatial arrangement of visual stimuli, such as structural discrimination tasks (Sanderson et al, 2006; Aggleton et al., 2007), but not other configural discrimination tasks such as the biconditional discrimination. These findings therefore strengthen the view that the relational memory difficulties seen in ASD are potentially due to compromised hippocampal function.

6.1.2. Experiment 3

Experiment 3 administered another test of relational memory, the transitive inference task, to typically-developing participants, and participants with ASD and reduced language abilities. Participants were first trained on four adjacent pairs of stimuli that were presented

in sequential order. The test phase consisted of the previously seen adjacent stimuli, along with new stimulus pairs created by re-pairing the adjacent stimuli to create pairs that required inference from the adjacent pairs about the relations between them to solve. Participants were required to use the knowledge gained during the training phase about which stimulus of an adjacent pair was reinforced. The prediction was that, since previous research showed that transitive inference is impaired in those with hippocampal damage, along with previous research from the animal literature that sociability plays a role in transitive inference, there would be impaired performance in transitive inference in individuals with ASD and reduced language. A further prediction was that, in the event that they were able to solve a transitive inference task, that they would use an associative, pair-by-pair strategy to solve the task.

The findings from Experiment 3 largely confirm this prediction. During the training phase, it was found that while the typically-developing participants were more accurate overall, both groups performed well above chance levels, but also found the middle training pairs equally difficult, appearing to indicate that an associative strategy was being used by both groups, rather than encoding of the whole sequence in memory. This finding carried through to the test phase, which found that, although the typically-developing participants were significantly more accurate overall, and both groups performed well above chance overall for the two trial types (adjacent and transitive), both groups performed the inner transitive (BD) pair at chance level. This is a strong indication that both groups were using an associative strategy. During the end task however, in which participants were asked to rearrange the previously seen pictures in order, the ASD group were found to be less accurate at reconstructing the overall order of the stimuli, suggesting that the typically-developing participants may have encoded the whole sequence; this is consistent with the idea that language is important in the construction of relational strategies.

These findings deviate from those found by Solomon et al. (2011), which showed that adults with ASD used a flexible relational strategy to solve the transitive inference task. However, as that study used high-functioning, linguistically-able adults with ASD, it would suggest that language ability may be a factor in strategy choice. This task would appear to be an effective test of relational memory in ASD and may help to further strengthen the view of relational memory impairments in ASD as caused by potentially compromised hippocampal function.

6.1.3. Experiments 4 and 5

Experiment 4 administered an incidental test of relational memory to typically adults and high-functioning adults with ASD, adapting a task which tested the existence of a novelty preference by measuring eye movements. Photos of everyday objects were shown against different coloured or patterned backgrounds, and the background on which the objects were presented was manipulated to create two conditions: a same-context condition, in which the background on which the pair of objects was presented was the same as the background on which the single object was presented, and a different-context condition, in which the background on which the pair of objects was presented was different to the background on which the single object was presented. The prediction for Experiment 4 was that, since individuals with ASD demonstrate memory patterns that are consistent with compromised hippocampal function, they would display no novelty preference in the different-context condition. Contrary to predictions, no group differences were found in Experiment 4, with both groups displaying a significant novelty preference in both conditions.

Experiment 5 administered the identical test of implicit relational memory to typically-developing children and children with ASD and reduced language abilities. Again, the prediction was that the ASD group would show no novelty preference when the

background on which a stimulus was presented changed from familiarisation to test. Findings from Experiment 5 deviated from previous research, but mirrored those of Experiment 4, in that both groups displayed a significant novelty preference in both conditions.

This task was successful in eliciting a significant novelty preference from both groups in both conditions, demonstrating the task to be an effective incidental and non-verbal measure of relational binding. Taken on their own, the findings that there was no impairment in context-based novelty preference may suggest that individuals with ASD are cognitively unrelated to individuals with hippocampal damage. However, considering the findings from the previous experiments, it may be possible that in individuals with ASD, the functions of the hippocampus are selectively compromised, with some remaining intact.

6.2. Relation to relational memory research

Research into relational memory in ASD demonstrates characteristic impairments, such as impaired recognition of combinations of features of visual stimuli (Bowler, Gardiner & Gaigg, 2008; Bowler et al., 2014; Ring et al., 2015), and lack of ability to use category information to aid free recall (Bowler, Matthews & Gardiner, 1997). These abilities appear to be mediated by the hippocampus, the brain region that encodes items and their relations for flexible later use (Eichenbaum, 2000; Opitz, 2010; Bird, 2017). The characteristic impairments found in ASD appear to point to a potential dysfunction with the hippocampus (Nicolson et al., 2006; Cooper et al., 2017). Overall, the current research appears to strengthen this view. Experiments 1, 2, and 3 largely replicate previous findings of relational memory impairments in high-functioning individuals with ASD. Although the findings from Experiments 4 and 5 appear to contrast with previous findings, they may imply a dissociation between different levels of awareness of relations between items. Individuals with ASD may

demonstrate implicit awareness of the relations whilst also demonstrating an impairment in their ability to explicitly use these relations in order to solve a test of relational memory.

6.3. Limitations of the current research

There were several limitations that were encountered as part of the current research. Chief among these was the issue of matching participants. The original intention was to test several different groups, matched on different psychometric measures: a typically-developing group of children matched on age, non-verbal and verbal ability with a high-functioning group of children with ASD, and a group of children with a non ASD-related intellectual disability, such as Down syndrome, matched on age, non-verbal and verbal ability with a lower-functioning group of children with ASD. However, it was not possible to recruit enough participants for each group to function as a sufficient comparison for the groups that were used; matching was only able to take place between typically-developing children and children with ASD on non-verbal ability. This meant that there was the possibility that the general level of functioning was lower in the ASD group, and that any individual differences found could have been attributed to this. As this was known about at the recruitment stage, care was taken to match children on a non-verbal task that was very similar to the experimental tasks, hoping to equate the groups' ability and therefore negate the potential that the typically-developing group would be at an advantage for the experimental tasks.

Another limitation found was that, although originally conceived as a way of adapting non-verbal tests of relational memory that could be used with participants at all levels of language ability, verbal instructions (though simple) still made up part of the task procedures. This means that, although the ASD group were found to have significantly reduced language abilities compared to the typically-developing group, the tasks could not be used with those participants who were completely non-verbal. This is a known issue when recruiting from

special populations, and unfortunately makes it very difficult to conclude that impairments found within the tested group are applicable across the whole of the autism spectrum.

6.4. Future directions

Because of the limitations found in the current research, there are various opportunities for future research to potentially support the findings demonstrated here. To try to extend these findings, recruitment should be expanded to include more verbally-able children with ASD, as well as children with a non ASD-related intellectual disability, such as Down syndrome. This would mean that more rigorous matching can take place, and the view that the differences found here are not simply due to differences in the general level of functioning can be further strengthened.

Also, as these were measures of relational memory, an ability demonstrated to be mediated by the hippocampus, it may be beneficial to administer the adapted paradigms detailed here, including task procedures, to hippocampally-damaged human participants. This would have the potential to bolster the view that the tasks used in the current research are effective measures of relational memory.

6.5. Conclusion

Evidence from memory studies demonstrating impaired relational processing has most commonly been based on the learning of verbal material (such as lists of words) by verbally-able participants with ASD, who are matched to a control group on full-scale IQ scores, which limited commentary on the universality of these difficulties across the spectrum. This research aimed to adapt non-verbal tests of relational memory for use with individuals with ASD who also have language deficits. This research has shown the paradigms adapted here to be effective measures of relational memory, which are suitable for

use with all individuals with ASD, at any level of functioning. These findings extend the previous research demonstrating characteristic impairments in relational memory in high-functioning individuals with ASD, to include individuals with ASD who would be considered lower-functioning. The research also supports the view that individuals with ASD have potentially compromised hippocampal function.

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Appendices

Appendix 1: Letter of consent to autism schools

CITY UNIVERSITY LONDON

THE AUTISM RESEARCH GROUP

Department of Psychology

City University

Northampton Square

Name and address

Date:

Dear [name],

I am currently undertaking a research project within the Autism Research Group at City University London. As you will know, investigations involving children who have developmental delay in addition to autism has been relatively neglected, with research tending to focus on individuals at the higher-functioning end of the spectrum. This is regrettable because better understanding of the learning and memory difficulties experienced by these young people would provide valuable input to remedial interventions and make some small contribution to improved quality of life for them and their families.

I am writing to ask whether you would be willing to help me recruit some young people from [school name] to take part in this study, and subsequently to allow me to test them individually in school. I am looking for participants between the ages of 11 and 16, with a diagnosis of autism and mild to moderate learning difficulties. If you are willing to make an initial contact with parents on my behalf, and if parents give their fully informed consent for me to see their child in school, I would visit them for approximately four short sessions throughout the term (at the discretion of yourself and their teacher).

The tasks all involve the presentation of simple visual stimuli on a touchscreen computer; participants are rewarded with stickers at the end of each task. We have many years of experience of working with a broad age range of children, and young people with diverse behaviours. Children usually enjoy working with us; however, if they show reluctance at any time, there is no obligation for them to continue. Individual results and names are not used in any documents or reports resulting from the study.

I would be more than happy to meet with staff and parents to discuss my research further, without any obligation on their part, and to answer any questions they may have. Please do not hesitate to contact me if you have any further questions; I look forward to hearing from you.

Kind regards

Claire Thomas
City University London
Email: [redacted]

Appendix 2: Letter of consent to mainstream schools

CITY UNIVERSITY LONDON

Department of Psychology

City University

Northampton Square

London EC1V 0HB

Name and address

Date:

Dear [name],

I am currently undertaking a research project within the Department of Psychology at City University London. I am very interested learning and memory in school-aged children. I believe that better understanding of the learning and memory characteristics in young people would provide valuable input to learning in school, and possibly help to provide remedial interventions for those who need it.

I am writing to ask whether you would be willing to help me recruit some young people from [school name] to take part in this study, and subsequently to allow me to test them individually in school. I am looking for typically-developing participants between the ages of 4 and 11. If you are willing to make an initial contact with parents on my behalf, and if parents give their fully informed consent for me to see their child in school, I would visit them for approximately four short sessions throughout the term (at the discretion of yourself and their teacher).

The activities involve the presentation of simple visual stimuli on a touchscreen computer; participants are rewarded with stickers at the end of each task. We have many years of experience of working with a broad age range of children, and young people at all levels of ability. Children are usually happy to work with us, and enjoy the fact that they are helping to contribute to science. However, if they show reluctance at any time, there is no obligation for them to continue. Individual results and names are not used in any documents or reports resulting from the study.

I would be more than happy to meet with staff and parents to discuss my research further, without any obligation on their part, and to answer any questions they may have. Please do not hesitate to contact me if you have any further questions; I look forward to hearing from you.

Kind regards

Claire Thomas
City University London
Email:

Appendix 3: Parent/carer consent letter

Department of Psychology
City University
Northampton Square
London EC1V 0HB

Claire Thomas
Tel: [redacted]
[redacted]

Dear Parent,

I am currently undertaking research which looks at learning and memory in children. My work involves comparing the memory performance of children who are typically developing, with the performance of children who have developmental disorders such as autism. I have been in contact with [HT] at [SCHOOL NAME], who gives the research [THEIR] full support, and so I am now writing to you in order to seek permission to include your child in this research. The research will be carried out during the school day, and I will work with your child's teacher to ensure that there is minimal disruption to the school day; also, if your child seems reluctant any point, they would not be compelled to participate. The tasks involve choosing between simple geometric shapes on a touchscreen computer. Stickers will be given to each child who takes part, and at the end of the research, children will also receive a £5 book token and a certificate of achievement from City University.

All information collected is strictly confidential, names of participants are replaced with codes, and only group averages are reported, meaning that no one child's data are published. At the end of testing I will be happy to come into the school to provide feedback on the overall findings of the research, and if you would like feedback on your child's performance on any of the tasks, I would be able to provide this.

I would be very grateful if you would give permission for your child to participate in this research, using the form attached. Research such as this provides important input into the field of developmental disorders and also has practical application to special needs education. If you would like more information or have any questions about this research, please do not hesitate to contact me on [redacted] or [redacted], or at my email address [redacted]. Alternatively you may contact me by post at the above address.

Yours sincerely

[redacted]

Claire Thomas

Postgraduate Researcher

Department of Psychology

City University London

Department of Psychology

City University

Northampton Square

London EC1V 0HB

City University Research Project – Parental Consent Form

This research has been approved by the Research and Ethics Committee of the Department of Psychology of City University London (project approval number PSYETH 11/12 010/015).
If you have any comments, concerns or observations about the conduct of the study, please contact Peter Aggar, the Secretary to the Committee, quoting the above project approval number.

Postal Address: Peter Aggar
Secretary to Psychology Department Research and Ethics Committee
School Office
Schools of Arts and Social Sciences
City University
Northampton Square
London EC1V 0HB

Telephone: [redacted]

Form to be returned by ……

Please fill in the details below:

Your child's name: ……

Please delete as applicable:

I **DO/DO NOT** want my child to take part…… (Your signature)

If you **would** like your child to take part, please fill in the details below:

Do you give permission for your child's school to have individual feedback on your child's performance in the tasks? YES ☐

NO ☐

Do you give permission for the Autism Research Group to contact you again about future research?

YES ☐

NO ☐

Appendix 4: Consent form for adults - visual paired comparison task

CITY UNIVERSITY LONDON

THE AUTISM RESEARCH GROUP

Department of Psychology

City University

Northampton Square

Consent Form

Title of Project: **Flexible Relational Processing in Adults with Autism Spectrum Disorder.**

Name of Researcher. Claire Thomas and Dermot Bowler

Please initial the boxes to indicate that you have read the relevant sections of this consent form.

I confirm that I have read the information sheet for the above named study. I have had the opportunity to consider the information and ask questions and have had these answered satisfactorily by one of the researchers. ☐

I understand what I will be asked to do during the study. ☐

I understand that my participation is voluntary and that I am free to withdraw at any time, without giving any reason. ☐

I understand that all individual information collected about me in this study will be kept strictly confidential. The information collected about me will only be used for research purposes and my personal details will only be available to members of the Autism Research Group. ☐

I understand that the results of this study may be shared with other research groups but that these results would be anonymised. My personal details will never be passed on to other researchers unless I give my written consent. ☐

I agree to take part in this study.

_____	_____	_____
Name of Participant	Date	Signature
_____	_____	_____
Name of Person Taking Consent	Date	Signature

Appendix 5: Information sheet for adults – visual paired comparison task

CITY UNIVERSITY LONDON

THE AUTISM RESEARCH GROUP

Flexible Relational Processing in Adults with Autism Spectrum Disorder

Claire Thomas
Professor Dermot Bowler

This study examines the way you look at single pictures and pairs of pictures. You will be presented with a sequence of pictures presented either singly or in pairs and asked to look at them. Your eye movements will be measured by a small device attached to a baseball cap that you will be asked to wear.
For your participation you will be paid a rate of £8 per hour and any expenses you incurred on travelling here will be reimbursed.
If you are in any way uncomfortable with this study or would prefer not to participate you do not have to take part. It is also important that you understand that you are free to stop the study at any time and that you will not suffer any penalty for doing so. If you feel you do not understand what we are asking you to do, please do not hesitate to ask for advice. If you would like to take a break at any time, or stop testing and go home, you are free to do so without any penalty.

All individual information collected about you will be kept strictly confidential and will not be shown to other people with your name attached unless you give your permission in writing; however it is possible that data may be re-used as part of a wider project in the future. We anticipate writing up our findings to be published in an academic journal, however please note that confidentiality of all participants will be maintained – all of the data obtained from individual participants is immediately made anonymous, and results are only reported that relate to group averages – so no one individual's data is published.
The information collected about you will only be used for research purposes and will only be viewed by those involved in this study including Claire Thomas and Professor Dermot Bowler from City University. If you have any questions please just ask either in person, by telephone ([redacted] or email ([redacted].
You will be fully debriefed at the end of the study (or before should you decide to withdraw). We hope to publish findings from this study in an academic journal and overall results (i.e. not individual) from the study will be available on request.

[redacted] or telephone [redacted]

The study will take place in DG10 (Ground Floor Social Sciences Building) and take around 30 minutes for you to complete.

If there is an aspect of the study which concerns you, you may make a complaint. City University has established a complaints procedure via the Secretary to the Research Ethics Committee. To complain about the study, you need to phone [redacted] You can then ask to speak to the Secretary of the Ethics Committee and inform them that the name of the project is Flexible Relational Processing in Adults with Autism Spectrum Disorder. You could also write to the Secretary at:

Anna Ramberg - Secretary to Senate Ethics Committee
CRIDO
City University
Northampton Square
London, EC1V 0HB
Email: [redacted]