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Relational Memory Processes in Adults with Autism Spectrum Disorder

Melanie Ring

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Autism Research Group

Department of Psychology

City, University of London

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Declaration

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Abstract

Research on memory in Autism Spectrum Disorder (ASD) points to difficulties in memory for personal experiences (episodic memory - EM). In particular, difficulties were found for the processing of relations between units of material leaving memory for single items mostly intact. The aim of this thesis was to examine EM in ASD further by investigating the influence of meaning, type of material, and relations, and by assessing the influence of complexity, executive functions, and attention on memory, learning, and spatial navigation in ASD. In addition to memory behaviour, eye movements were measured. It was found that the EM impairment in ASD adults with average intellectual abilities persisted across a range of materials and types of relations, and that item memory was also affected when using tests of similar complexity to relational memory tests. Eye movements indicated attentional differences in ASD that may have had an impact on the observed difficulties, and they indicated that memory difficulties went beyond explicit deliberate retrieval of information also affecting implicit memory and, therefore, suggesting that also encoding and post-encoding processes may work differently in ASD. Spatial navigation was particularly affected by executive function and item memory difficulties in ASD, and structural learning may be the fundamental mechanism that underlies the cognitive difficulties observed in ASD. Future research should concern the development and application of measures for less verbal and/or intellectually able ASD individuals and the investigation of how the studied processes are affected by ageing in the ASD population. In addition, training and support strategies should be developed to investigate whether memory difficulties in ASD are caused by a processing bias or a deficit and to attempt to alleviate them. Finally, the investigation of memory encoding and consolidation is needed to test whether these processes operate differently in ASD and, if so, how they could be improved.

List of Abbreviations

ADHD	Attention Deficit/Hyperactivity Disorder
ADI-R	Autism Diagnostic Interview-Revised
ADOS	Autism Diagnostic Observation Schedule
AE	Egocentric switch
ANCOVA	Analysis of Covariance
ANOVA	Analysis of Variance
ABM	Autobiographical Memory
AQ	Autism-Spectrum Quotient
ASD	Autism Spectrum Disorder
AtoM	Attention to Memory
BD	Block Design
BPVS	British Picture Vocabulary Scale
CA	Chronological Age
CANTAB	Cambridge Neuropsychological Test Automated Battery
cd/m^2	candela/square meter
CI	Confidence Interval
CMS	Children's Memory Scale
CR	Correct Rejection
CTT	Color Trails Test
CTT2	Color Trails Test Trial 2
CVLT	California Verbal Learning Test
DD	Developmental Delay
df	degrees of freedom
DSM-5	Diagnostic and Statistical Manual of Mental Disorders 5

DSM-IV	Diagnostic and Statistical Manual of Mental Disorders IV
DSM-IV-TR	Diagnostic and Statistical Manual of Mental Disorders IV - text revision
E	Exclude
EA	Allocentric switch
EEG	Electroencephalogram
EF	Executive Function
EFT	Episodic Future Thinking
EM	Episodic Memory
EPF	Enhanced Perceptual Functioning
ERP	Event-Related Potential
f	female
F	Familiarity
FA	False Alarm
FIQ	Full-scale Intelligence Quotient
fMRI	functional Magnetic Resonance Imaging
GGC	Greenhouse Geisser Correction
H-FA	Hit rate minus False Alarm rate
Hits	Hit rate
Hz	Hertz
I	Include
IED	Intradimensional/Extradimensional shift task
ID	Intellectually Disabled
IQ	Intelligence Quotient
JR	Remember Justifications
K	Know

K-BIT	Kaufman Brief Intelligence Test
LIPS	Leiter International Performance Scale
LTM	Long-Term Memory
m	male
M	Mean
MA	Mental Age
MTL	Medial Temporal Lobe
η_p^2	partial Eta-Squared
N	Number
NIH	National Institute of Health
NVA	Nonverbal Ability
OA	Older Adults
OCD	Obsessive-Compulsive Disorder
PDD-NOS	Pervasive Developmental Disorder Not Otherwise Specified
PDP	Process-Dissociation Procedure
PFC	Prefrontal Cortex
PIQ	Performance Intelligence Quotient
PM	Procedural Memory
PPVT-III	Peabody Picture Vocabulary Test Third version
PRI	Perceptual Reasoning Index
PRS	Perceptual Representation Memory
R	Remember
Rec	Recollection
R/K	Remember/Know
ROI	Region of Interest

s	seconds
SD	Standard Deviation
SEM	Standard Error of the Mean
SLI	Specific Language Impairment
SM	Semantic Memory
SPCD	Social (Pragmatic) Communication Disorder
STM	Short-Term Memory
TD	Typically Developing
TD OA	Typically Developing Older Adults
ToM	Theory of Mind
TSH	Task Support Hypothesis
VA	Verbal Ability
VCI	Verbal Comprehension Index
VIQ	Verbal Intelligence Quotient
WAIS	Wechsler Adult Intelligence Scale
WAIS-III[UK]	Wechsler Adult Intelligence Scale Third UK version
WAIS-IV[UK]	Wechsler Adult Intelligence Scale Fourth UK version
WASI	Wechsler Abbreviated Scale of Intelligence
WCC	Weak Central Coherence
WCST	Wisconsin Card Sorting Test
WISC-III	Wechsler Intelligence Scale for Children Third version
WM	Working Memory
WMS	Wechsler Memory Scale
X^2	Chi-Squared

1 Chapter 1: Introduction

1.1 Autism Spectrum Disorder

1.1.1 What defines ASD?

Until 2013, autism was considered to be one among many pervasive developmental disorders diagnosed according to the Diagnostic and Statistical Manual of Mental Disorders IV text revision (DSM-IV-TR, American Psychiatric Association, 2000). Whereas difficulties in the three areas of social interaction, communication, and stereotyped behaviours, interests and activities (so called *autism triad*, Wing & Gould, 1979) were defining for autistic disorder and Asperger Syndrome, pervasive developmental disorder not otherwise specified (PDD-NOS) and childhood disintegrative disorder were characterised by difficulties in one or two of these areas respectively. Difficulties in communication, for example, inflexible usage of language or odd pronunciation, were not defined as limited to social situations, and this criterion could have been fulfilled by a delay or failure in language development (American Psychiatric Association, 2000). Difficulties in social interaction included a lack of relationships to peers and a disturbance in social and emotional reciprocity in contact with others (American Psychiatric Association, 2000). Stereotyped behaviours involved an insistence on sameness and the maintenance of rituals and dysfunctional habits (American Psychiatric Association, 2000). Asperger Syndrome did not have a language delay (American Psychiatric Association, 2000), and it was viewed as a milder form of autism (Ritvo, Ritvo, Gutherie & Ritvo, 2008). DSM-5 (American Psychiatric Association, 2013) now treats the term *Autism Spectrum Disorder* (ASD) as one disorder of neuronal and mental development, recognising the relevance of a shared underlying neurobiology (Kupfer & Regier, 2011). All individuals that clearly fulfilled the criteria of one of the above named diagnoses would nowadays be given the diagnosis of an ASD. ASD is defined by the two behavioural criteria of stereotypic routine-like behaviours, interests, and activities and difficulties in interaction

and communication with others (American Psychiatric Association, 2013). These criteria range in severity with the result that the disorder covers the whole range of language and intellectual abilities. This is why it is often called a spectrum of conditions.

A complete diagnostic assessment should include, next to a clinical assessment of behavioural features, a consideration of the developmental history of the individual, as reported by the parent (Falkmer, Anderson, Falkmer & Horlin, 2013; Mahjouri & Lord, 2012) or another close relative (Van Niekerk et al., 2011), as well as cognitive and language testing (Volkmar, Cook, Pomeroy, Realmuto & Tanguay, 1999). A reliable diagnosis is possible from the second year of life (Moore & Goodson, 2003), where the first signs of the disorder often are an abnormal language development and/or an unusual interest in objects rather than other people or situations involving other people (Howlin & Asgharian, 1999). Parent reports suggest that abnormalities may be present below the age of 1 year (Constanzo et al., 2015), but in practice a firm diagnosis is obtained only years later (Howlin & Asgharian, 1999). To account for the possibility that individuals show difficulties in social interaction and communication without the presence of stereotypic behaviours, either at present or in the past (American Psychiatric Association, 2013), a new diagnosis - Social (Pragmatic) Communication Disorder (SPCD) - was coined. Further, a diagnosis of Attention Deficit/Hyperactivity Disorder (ADHD) would now be given to an individual in addition to a diagnosis of ASD, if the individual fulfils criteria for both disorders (American Psychiatric Association, 2013).

Recent estimates show a 4:1 male to female ratio for ASD (Rivet & Matson, 2011), but it is unclear if the disorder is really more common in males, or if females are underdiagnosed because they are more social by nature and, therefore, seem less affected (Hiller, Young & Weber, 2014). Prevalence rates for all pervasive developmental disorders have risen in comparison to previous estimates from 0.19 % (Fombonne, 1999), over 0.3 - 0.6

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% (Fombonne, 2003), to recent estimates of 1.13 - 1.16 % (UK: Baird, 2006; US: Autism and Developmental Disabilities Monitoring Network Surveillance Year 2008 principal investigators, Centers for Disease Control and Prevention, 2012). The new estimates may reflect a real increase in the occurrence of the disorder, or they may be the result of a revision of diagnostic criteria, better recognition through increased awareness and knowledge about the disorder (Wing & Potter, 2002), differences in the use of diagnostic instruments and available services (Mahjouri & Lord, 2012), or misdiagnosis, and changes in cultural perceptions of 'abnormality' (Matson & Kozlowski, 2011). Prevalence rates may also be affected by dropout rates in the studies and changes in the rates at which individuals self-refer to diagnostic services (Bölte, Herbrecht & Poustka, 2007). Prevalence rates are as high as 2.6 - 2.7 %, if whole populations rather than high-risk samples are screened, as recent studies from South Korea (Kim et al., 2011) and Norway (Posserud, Lundervold & Gillberg, 2006) suggest.

Language and intellectual impairments are important features of the disorder. About half of individuals with ASD present language impairments (Loucas et al., 2008) and more than half have intellectual abilities below the mean (estimates range from 24 % - Idring et al., 2015; 55 % - Baird et al., 2006; 59 % - Kim et al., 2011; to 68 % - Yeargin-Allsopp et al., 2003). For those without marked intellectual disability, differences in the use of language or in its understanding are likely (Tager-Flusberg & Joseph, 2003). Therefore, a large proportion of individuals with ASD are under-researched because of their limited language and/or intellectual abilities.

The cause of ASD is still unknown. The high heritability found in twin studies (Ronald & Hoekstra, 2011) led researchers to suspect a genetic cause, but apart from a few rare cases, where individual genetic factors were identified, when ASD co-occurred with another disorder that has a genetic cause, like fragile X (Belmonte & Bourgeron, 2006), many

different genetic factors have been reported to be involved in the development of ASD (Waterhouse, 2013). A large number of non-specific environmental factors have also been implicated in the development of ASD, including advanced maternal (Shelton, Tancredi & Hertz-Picciotto, 2010) and paternal age (Durkin et al., 2008; Hultman, Sandin, Levine, Lichtenstein & Reichenberg, 2011), the mother taking valproate during pregnancy (Christensen et al., 2013; Hallmayer et al., 2011), and others (see Mandy & Lai, 2016 for further details). Finally, gene-environment interactions may also play a role in the emergence of ASD, in that a specific gene alternation makes the individual more vulnerable for environmental risk factors (Chaste & Leboyer, 2012).

Individuals with ASD have been found affected by a higher percentage of mental and physical health conditions (70 % have one more, 41 % two or three additional conditions - Simonoff et al., 2008) in comparison to typically developing (TD) individuals. In adults with ASD, rates were highest for anxiety, depression, Obsessive-Compulsive Disorder (OCD), and schizophrenia (Croen et al., 2015), as well as seizures, epilepsy, and sleep problems (Levy, Mandell & Schultz, 2009; Tuchman & Rapin, 2002). In a longitudinal study, only about 30 % of ASD individuals were successfully and permanently integrated into employment (including supported and voluntary work; Howlin, Goode, Hutton & Rutter, 2004). However, about 77 % of persons with ASD were not living independently, and they continued having difficulty in establishing relationships throughout life (Howlin et al., 2004).

1.1.2 Critical discussion of DSM-5 criteria

Difficulties in distinguishing between the different DSM-IV diagnoses for pervasive developmental disorders, clinically (Lord et al., 2011; Mahjouri & Lord, 2012; Wing, Gould & Gillberg, 2011), and high prevalence rates of PDD-NOS (Mahjouri & Lord, 2012), led to the suggestion that at least some individuals may have been misdiagnosed (Buitelaar, van der Gaag, Klin & Volkmar, 1999; S. D. Mayes, Black & Tierney, 2013; S. D. Mayes et al., 2014;

I. C. Smith, Reichow & Volkmar, 2015). The unification of these subcategories under the single umbrella of ASD in DSM-5 presented better construct validity (i.e., an instrument measures what it is supposed to measure - De la Marche, Noens, Boets, Kuppens & Steyaert, 2015; Harstad et al., 2015; Mandy, Charman & Skuse, 2012), as well as increased specificity (i.e., reducing the number of individuals receiving the diagnosis even though they are not autistic) of ASD diagnostic criteria. However, there are also reports of a decreased sensitivity (i.e., reducing the number of people that should have received a diagnosis because they are autistic but do not receive one) for individuals with "milder" forms of ASD (Young & Rodi, 2014), higher Intelligence Quotients (IQs; McPartland, Reichow & Volkmar, 2012), and older age (Wilson et al., 2013), which were avoided by an adjustment of diagnostic instruments (Kent et al., 2013).

Despite reports that ASD individuals, using DSM-5 criteria, seemed more severely affected by stereotypic (Beighley et al., 2014), as well as socially inappropriate behaviours (Beighley & Matson, 2014), ADHD symptoms (Konst, Matson, Goldin & Rieske, 2014), tantrums, avoidant behaviours, anxiety, and eating or sleeping problems (L. W. Williams, Matson, Beighley, Rieske & Adams, 2014), DSM-IV and DSM-5 research samples have been found to be 93 % comparable in terms of clinical presentation (Mazefsky, McPartland, Gastgeb & Minshew, 2013), when using a combination of Autism Diagnostic Observation Schedule (ADOS; Lord et al., 1989) and Autism Diagnostic Interview-Revised (ADI-R; Rutter, Le Couteur & Lord, 2002) to establish a diagnosis. Finally, SPCD has been shown to be a separate disorder, empirically, in that affected individuals did not show any repetitive behaviours (Gibson, Adams, Lockton & Green, 2013), and they presented fewer social difficulties compared to ASD individuals (Whitehouse, Watt, Line & Bishop, 2009), but more social difficulties compared to individuals with Specific Language Impairment (SLI; Gibson et al., 2013).

Following the definition of ASD according to DSM-5, this thesis will generally refer to individuals with ASD, summarising all previous subcategories, including Asperger syndrome, autism, and PDD-NOS. Having established a general understanding of what is nowadays referred to as ASD, its prevalence, causes, and how new diagnostic criteria might stand in relation to previous ones, the thesis will now move on to discuss cognitive accounts of the condition.

1.2 Cognitive theories of ASD

1.2.1 Theory of Mind Deficit

The term *Theory of Mind* (ToM) was coined by Premack and Woodruff (1978). People possess a ToM if they can infer mental states, such as knowing, believing, feeling, or thinking, to themselves and others. It is called a theory because one cannot directly see mental states, but one can make predictions about them and test these (Gopnik & Wellman, 1992; Perner, 1991; but see Carpendale & Lewis, 2004; Gallese & Goldman, 1998; Hobson, 1991; Leudar & Costall, 2009 for further discussion of the mechanisms underlying our understanding of mental states). Researchers began to study ToM in ASD because social impairments had been identified as the key behavioural feature of the condition (Wing & Gould, 1979), and being social implies understanding other minds. The first formal assessment of ToM in ASD was done by Baron-Cohen, Leslie and Frith (1985), who adapted a false belief paradigm by Wimmer and Perner (1983), who had found that typical children developed false belief understanding around the age of 4 years. False belief is defined as the understanding that others can hold beliefs that are wrong. The task used is, nowadays, widely referred to as the Sally-Anne task. Baron-Cohen et al. (1985) found that the majority of their TD and Down syndrome children passed the test, whereas most ASD children failed it, even though they had higher intellectual abilities than the control groups. The finding has since

been replicated various times with different paradigms as well as different groups of participants of various ages and IQ levels. It was concluded, that individuals with ASD have problems with ToM. However, only marginal associations have been found between these problems and the social difficulties ASD individuals face (Tager-Flusberg, 2003), suggesting that ToM difficulties constitute only part of the cognitive difficulties underlying core clinical features of ASD. In fact, other areas of cognition sometimes difficult for ASD individuals, such as memory and executive functions (EFs), as well as language, and the ability to process complex stories that include abstract mental state words (Tager-Flusberg, 2007), seem relevant factors in solving ToM tasks, and Pellicano (2010) found that EFs and local processing are predictors of later ToM performance. Frith and Frith (2003) found that ASD, as opposed to TD individuals, approached ToM tests as a general (complex) problem rather than one that needed social insight, and Bowler, Briskman, Gurvidi and Fornells-Ambrojo (2005) found high correlations between performance on a mechanical analogue of a false belief task without mental states and performance on the Sally-Anne task. Complexity in the Bowler et al. (2005) paradigm was defined as a series of conditional rules or relations that needed to be formed (Halford, 1992), and difficulty with the use of these is not specific to mental states but is rather a feature of general cognition. Another criticism of the account is, that a ToM deficit has been found not to be specific to ASD, as it was also found in other disorders (for a review see Korkmaz, 2011), such as schizophrenia (see Brüne, 2005 for review), ADHD (Saeedi, Noorazar, Bafandeh, Taheri & Farhang, 2014), or deaf children of hearing parents (Schick, De Villiers, De Villiers & Hoffmeister, 2007)[1], and sometimes even TD individuals showed ToM difficulties (Ozonoff, Pennington & Rogers, 1991). Considering that ToM difficulties only become apparent around the age of 4 years, when the majority of

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[1] A delay in ToM development in this study was only found for deaf children of hearing parents. As opposed to these, deaf children of deaf parents performed similarly to TD children. This striking result gives some more indication that language seems to be a crucial factor in success on ToM tasks.

TD children is passing false belief tests (Korkmaz, 2011), and keeping in mind that ASD can reliably be diagnosed from around 2 years of age (Moore & Goodson, 2003), ToM difficulties cannot be the cause for social-communication impairments that start emerging much earlier (Boucher, 2012). The theory's greatest restriction may be its focus on social and communicative behaviours, which are part of the diagnostic criteria, but which do not explain difficulties that persons with ASD show in other "non-social" areas of behaviour, such as restricted and repetitive behaviours or emotion-processing (Hobson, 1993). Neither does the ToM deficit theory capture the strengths in some areas of cognition that are characteristic of individuals with ASD (Frith & Happé, 1994). To meet these criticisms other accounts were developed.

1.2.2 Executive Dysfunction

Another area, where ASD individuals have been found to show difficulties, is *Executive Function* (EF). EFs are problem-solving skills or functions that support actions to achieve distant goals, which include "planning, impulse control, inhibition of prepotent but irrelevant responses, set maintenance, organised search, and flexibility of thought and action" (Ozonoff et al., 1991, p. 1083). Pennington and Ozonoff (1996) also included "interference control, […], integration across space and time, […], and working memory" (p. 55) in their definition of EFs. The aim of the account was to explain some of the behaviours of ASD individuals that the ToM account does not explain and to find a difficulty that is common to all individuals with ASD. While some individuals with ASD passed ToM tasks (e.g., Baron-Cohen et al., 1985; Bowler, 1992; Ozonoff et al., 1991), Ozonoff et al. (1991) found that almost all participants in their study (96 %) were impaired in specific measures of EFs. Difficulties in EFs in ASD have been shown in the areas of mental flexibility, i.e., the ability to react flexibly to changes in the test, for example, using the Wisconsin Card Sorting Test (WCST; Rumsey, 1985; Rumsey & Hamburger, 1988; 1990), as well as planning and

inhibition of a prepotent response (Hill, 2004a). There are, however, some issues with the measurement of EFs. Russell, Jarrold and Hood (1999) argued that on some tasks children with ASD show EF deficits because the rules seem arbitrary to them. For example, on the WCST, where participants are asked to sort cards according to an unknown rule, which they are supposed to infer from feedback following their sorting decisions, there is no obvious reason why the rules according to which cards should be sorted, should change at a certain point. In addition, tasks, such as the WCST, tackle many different EFs (e.g., inhibition, working memory, etc.), making it difficult to ascertain exactly where problems lie (Hill, 2004a). Therefore, systematic investigations are needed to find the specific processes that are difficult for ASD individuals. Further, the executive dysfunction view does not account for all difficulties ASD individuals show, such as in the area of cognition (Frith & Happé, 1994), or in the core diagnostic areas, as EFs do not explain any significant variance in social interaction or repetitive behaviours in ASD in empirical investigations (Joseph & Tager-Flusberg, 2004). In addition, difficulties in EFs are not found in all ASD samples (e.g., Minshew, Goldstein, Muenz & Payton, 1992 using the WCST), and EF difficulties are also not specific to ASD, as they were also found to be evident in other disorders, such as frontal lobe damage (Alvarez & Emory, 2006), schizophrenia (Orellana & Slachevsky, 2013), ADHD (Willcutt, Doyle, Nigg, Faraone & Pennington, 2005), Parkinson's disease (Dirnberger & Jahanshahi, 2013), and groups such as typical Older Adults (OA; Hedden & Gabrieli, 2004). In general, although EF tests are supposed to measure frontal lobe functions, they are usually complex tasks, and individuals can fail on these tasks because of a disturbance in a number of different processes that do not need to have anything to do with frontal lobe functions (Pennington & Ozonoff, 1996), especially when control measures are lacking that are similar in complexity but are not supposed to tap EFs. The issue of complexity is, therefore, discussed in the next section.

1.2.3 Complex Information Processing Deficit

The theory of a deficit in *Complex Information Processing* arose as a critique of the two previously discussed cognitive models (ToM, EF), arguing that they only look at one potential area of deficit in ASD (D. L. Williams, Minshew & Goldstein, 2015). In a thorough assessment of language and memory in the same ASD sample (Minshew et al., 1992; Rumsey & Hamburger, 1988), the authors found mixed results in that ASD participants performed well on tests measuring more automatic processes, such as reading a text or spelling words without necessarily understanding the meaning, but they did worse than TD participants on tests that necessitated comprehension, interpretation, and inference of information, as in reading a text so one can answer questions about the text (Minshew, Goldstein, Taylor & Siegel, 1994; Minshew, Goldstein & Siegel, 1995). The second kind of task was defined as more complex and the idea was put forward that ASD individuals show difficulties in processing complex information (Minshew & Goldstein, 1998; Minshew et al., 1994). In this context, complexity was defined in various ways, including a large number of units to be processed, the requirement for this information to be organised in some way or, at a neural level, by the involvement of interactions between distant areas in the brain (D. L. Williams et al., 2015). These various definitions make it difficult to disprove the account. There is a danger of circularity in concluding that ASD individuals show difficulties with complex tasks, and when they cannot solve a task, one concludes that the task is complex without clearly operationalising or defining complexity. In addition, the reported deficits in complex tasks in ASD were at least partly explained by the tests' high demands on working memory (Minshew et al., 1995) and, therefore, by the above described deficit in EFs in ASD.

The following three theories try to explain cognitive functioning in ASD by focussing on processes where ASD individuals were found to be superior.

1.2.4 Weak Central Coherence

Frith and Happé (1994) devised the theory of *Weak Central Coherence* (WCC) in ASD in an attempt to account for non-social behaviours that are not explained by deficits in ToM, as well as to explain the performance of individuals, who pass ToM tasks (such as in Baron-Cohen et al., 1985; Bowler, 1992; Ozonoff et al., 1991). Frith (1989) described central coherence as a processing style of TD individuals that draws together various pieces of information to present them as a whole with an overall meaning. A deficit in this processing style in ASD was inferred on the basis that ASD individuals tend to focus on details. Because of criticism and contradictory findings, Happé (1999) revised the theory to say that WCC is a preference for a processing style rather than a deficit in ASD cognition. Support for the WCC theory was found in superior performance in ASD compared to TD on tasks like the embedded figures test (e.g., Shah & Frith, 1983), where participants are asked to find a hidden figure in a larger design, or the block design subtest of the Wechsler Intelligence test (e.g., Shah & Frith, 1993)[2], where participants are asked to build a design from a template with plastic cubes, as well as in difficulties in ASD in tasks that necessitate one to process information in context, for instance, to disambiguate the meaning of a word in a sentence based on the overall meaning of the sentence (e.g., Frith & Snowling, 1983). Later research, however, showed that ASD participants respond to global information, for example, when they are instructed to do so (Koldewyn, Jiang, Weigelt & Kanwisher, 2013; L. Wang, Mottron, Peng, Berthiaume & Dawson, 2007). Similarly, the same ASD participants, who showed a local bias in one task, presented coexisting intact global performance in another task (Hadad & Ziv, 2015; Plaisted, Swettenham & Rees, 1999; Rondan & Deruelle, 2007). Also, WCC is not specific to ASD (Mottron, Dawson, Soulières, Hubert & Burack, 2006), as

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[2] A recent meta-analysis of visuo-spatial performance in ASD, however, showed that based on previous evidence only performance on the block design test is superior in ASD (Muth, Hönekopp & Falter, 2014).

there have been demonstrations of a local bias in other disorders, such as Williams Syndrome (M. A. Porter & Coltheart, 2010).

1.2.5 Increased Perceptual Discrimination

The *Increased Perceptual Discrimination* theory originated in the finding of poor transfer from a training situation to a new context in ASD participants (e.g., Swettenham, 1996), and the idea that ASD individuals process novel elements of a new situation or context well (Plaisted, O'Riordan & Baron-Cohen, 1998a). Thereby, they tend not to look for elements that are in common between training and a new context, leading to *Reduced Generalisation* (Plaisted et al., 1998a). According to this theory, ASD participants perform poorly if the training and transfer contexts share only few elements and the transfer context includes many new features. This is because persons with ASD prefer to process the new elements rather than the old ones. Such processing gives ASD individuals an advantage at discrimination tasks, for example, tasks asking participants to distinguish between different letters of the same colour or the same letters in different colours (Plaisted, O'Riordan & Baron-Cohen, 1998b), but gives them a disadvantage on tasks asking for shared features to be processed, such as the formation of prototypes for a face (Gastgeb, Rump, Best, Minshew & Strauss, 2009) or the categorisation of objects (Gastgeb & Strauss, 2012). Plaisted et al. (1998a) tested the theory with a perceptual learning task using highly similar images. ASD participants performed similarly well in discriminating images they had been trained on from novel images, whereas TD individuals benefitted from training and discriminated the images they were familiar with to a significantly better extent. A direct comparison of the two groups showed lower performance of ASD individuals on previously trained images but higher discrimination on novel images compared to TD participants. This finding led the authors to conclude that ASD individuals seemed to focus on the novel elements in all stimulus displays, and that they seemed to treat all problems as novel. This superior discrimination

performance was argued to underlie ASD individuals' outstanding performance on visual search (Kemner, van Ewijk, van Engeland & Hooge, 2008; O'Riordan & Plaisted, 2001), and embedded figures tasks (Plaisted, 2001), where ASD participants focus on non-shared features of stimuli in a search array or between target and background image. Increased discrimination was also found for the auditory domain, where ASD participants showed superior performance on discrimination of tone sequences. However, no between-group difference was found for the sense of touch (O'Riordan & Passetti, 2006). An alternative explanation for reduced generalisation was offered by Bott, Brock, Brockdorff, Boucher and Lamberts (2006), who suggested that ASD individuals use fewer attributes to judge the similarity of images. Ploog (2010) criticised the Perceptual Discrimination theory, by arguing that over-selectivity (i.e., elements are processed separately rather than as members of different categories), which lies at the basis of this theory, has been found in other disorders and is, therefore, not specific to ASD. Finally, Mottron et al. (2006) added that discrimination, which is at the centre of this theory, is only one process among many that they think are working differently in ASD. As an alternative, Mottron et al. (2006) developed *Enhanced Perceptual Functioning* (EPF) theory (Mottron & Burack, 2001; Mottron et al., 2006), which will now be discussed.

1.2.6 Enhanced Perceptual Functioning

EPF started off as a critique of the WCC account (Frith & Happé, 1994), and it was based on demonstrations that persons with ASD did not generally show a deficit in global processing (Mottron, Burack, Iarocci, Belleville & Enns, 2003; Mottron, Burack, Stauder & Robaey, 1999; Mottron, Peretz & Ménard, 2000; Ozonoff, Strayer, McMahon & Filloux, 1994). The central proposition of EPF is that an intact early developed low-level process, like the perception of physical properties of objects, such as colour, shape or size, takes over an impaired one, for instance, the perception of faces or emotions, and through experience over

time leads to an enhanced performance beyond the capabilities of TD individuals in a certain area of processing (Mottron & Burack, 2001). Deficits occur when these over-developed low-level processes, such as perceiving an object, interfere with higher-level processes, such as remembering an object, or when the preoccupation with perception, for example, looking at spinning objects instead of exploring the environment, hinders the development of other behaviours, such as pretend play (Mottron & Burack, 2001). This account offered an alternative to aspects of the Executive Dysfunction account in explaining problems in response inhibition, not with reference to an executive process, but with reference to ASD individuals' lower perceptual threshold that leads them to react to stimuli that TD individuals may not perceive. A criticism of the EPF account is that the authors, especially in the later version of the theory (Mottron et al., 2006), named too many possible mechanisms, which made the account harder to test and disprove. The use of savant skills[3] in the theory may explain the disproportionate prevalence of savant skills in the ASD population, but it may cut a bit short in explaining phenomena common to all autistic individuals, as research has found that a strength in one cognitive area in ASD did not always come with a corresponding weakness in another area and vice versa (Plaisted Grant & Davis, 2009). Further, recent meta-analyses found clear visuo-spatial superiorities for autistic individuals only in some tasks but not others (Muth et al., 2014), and they suggested neither a global deficit, nor a local superiority in ASD, but rather that ASD individuals were just slower at grasping the general meaning of information in context (Van der Hallen, Evers, Brewaeys, van den Noortgate & Wagemans, 2015). A possible reason is that ASD participants attend to information differently compared to TD individuals and this idea will be discussed in what follows.

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[3] Savant syndrome defines an exceptional ability in an individual with a developmental disability that is in contrast to its general cognitive abilities (Treffert, 2014). Savant skills have been reported in about 10 % of autistic individuals (e.g., Bölte & Poustka, 2004; Rimland, 1978), the number goes up to about 30 % if exceptional cognitive abilities like superior performance on the block design task are included (Howlin, Goode, Hutton & Rutter, 2009).

1.2.7 Atypical Attention

Allen and Courchesne (2001) suggested *Attention Dysfunction* to be responsible for the cognitive profile observed in ASD, as attention is the prerequisite for a lot of higher-order cognitive processes. In the case of *Selective Attention*, the authors argued that depending on the volume of the parietal lobe individuals with ASD are either be over- or under-selective (see also Townsend & Courchesne, 1994). Over-selectivity in this case means having a small attentional focus, which is an advantage in visual search tasks, where the focus needs to be on targets and the search needs to be shielded from distracters (e.g., Wainwright & Bryson, 1996). Regarding *Sustained Attention*, the authors referred to a study by Garretson, Fein and Waterhouse (1990) showing that rather than task complexity, motivation had an effect on attention. Wainwright and Bryson (1996) argued that difficulties in maintaining continuous attention in ASD only appear when social reward is used, because of abnormalities in limbic structures that process reward differently compared to TD individuals (Weinberger, 1993). In terms of *Spatial Attention*, ASD participants have shown difficulties to disengage attention (so called "sticky attention" - Allen & Courchesne, 2001), which was found to be related to the volume of the parietal lobe (Townsend, Courchesne & Egaas, 1996). In addition, rapid orienting to detect a briefly lasting stimulus or to discriminate was harder for ASD individuals with smaller cerebellar volumes, suggesting a role of the cerebellum in response preparation. Another difficulty in attention in ASD was found in *Shifting Attention* under time pressure, which is another function that may be supported by the preparatory actions of the cerebellum. Without this preparation, attention shifts are slowed and occur with more errors. Allen and Courchesne (2001) suggested that the difficulty demonstrated by the shifting attention task may be part of a more general problem in providing and adjusting cognitive resources quickly and accurately. Minshew and Goldstein (1998) criticised the literature on attention in ASD in arguing that the results were affected by the demands on working

memory and EFs of the tasks. As these are areas of difficulty in ASD as well, tasks need to be used that tease apart difficulties in different areas.

To conclude, all of the above-presented theories have stimulated a great deal of research and have shaped our current understanding of ASD. The theories were all significantly supported by neurological findings, suggesting that they each are important in their own right in covering aspects of ASD (Schroeder, Desrocher, Bebko & Cappadocia, 2010). Some are domain-specific (like ToM), and others are more domain-general (like WCC or EF). Some are focussed on higher-level cognitive domains (like ToM), some on lower-level ones (like EPF), and some are both (like WCC). But because ASD is complex and heterogeneous, none of the theories has been able to explain all its features. The question remains if it is possible to define one domain of functioning in which disturbances can explain all core features of ASD or if it is, as Happé, Ronald and Plomin (2006) have argued, time to give up on this idea and rather try to find separate theories to explain the triad of symptoms[4] in ASD.

A domain of functioning that was originally considered to be important in explaining the characteristics of ASD is memory, and it is now attracting new interest given that the theories described above have not developed explanations of ASD that encompass all or even most of its clinical features. A characteristic memory profile in ASD is now regarded as an important feature of the ASD phenotype. The study of memory in ASD makes sense, when one considers that memory is a domain-general process and, therefore, can account for difficulties in a wide range of domains. It includes both high- and low-level processes, because of distinctions of different memory systems and processes, it can be explored at several levels, enabling a fine-grained, theory-driven analysis, and it is central to almost everything people

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[4] At the time of the article, ASD was still defined by difficulties in the three areas of functioning of social interaction, social communication, and restricted and repetitive behaviours. Later with the DMS-5, the two areas of social interaction and communication were pooled into one criterion (see Section 1.1.1).

do. Apart from the obvious function of remembering the past, which is already important for the simplest tasks in everyday life, memory is also important for a whole range of other functions, such as planning for the future or imagining possible scenarios, which requires the re-configuration of elements of past experiences to derive possible non-experienced events that may happen in the future or that are fictitious. Memory depends on and contributes to a whole range of other psychological functions that have been discussed in detail earlier (see Section 1.2), such as EFs or attention. It is involved in complex reasoning, which is a process that stands at the core of deficits in ASD, such as ToM, and it might also help to explain the development of repetitive behaviours as the formation of habits. Finally, as the brain bases of typical memory are becoming better and better understood, it is possible to infer from memory atypicalities in ASD to underlying mechanisms and brain bases. In what follows, the thesis will start off with defining memory and will continue with memory findings and theories in ASD.

1.3 Memory

To look at memory as one unified system would be too simplistic. Different memory systems are supported by different underlying mechanisms and brain structures and this complexity has the advantage of enabling a fine-grained analysis of what might be working similarly or differently in ASD as opposed to TD individuals. Psychologists have taken a number of different perspectives on memory. One of the first models was the *multi-store memory model* (Atkinson & Shiffrin, 1968), which proposed a distinction between sensory, short-term, and long-term memory as separate stores that are ordered in a linear fashion. Information is fed into the system through the senses, when attended to in sensory memory, the information is passed on to short-term memory, and through rehearsal reaches long-term memory, where it is saved for an unlimited amount of time, or until it is retrieved again. If information is not

attended to or rehearsed, it becomes permanently lost. Research soon found that this model is too simplistic. Several separate stores for short-term (Baddeley, 2000), and long-term memory (Schacter & Tulving, 1994), have been proposed since and in addition to rehearsal, consolidation (Craik, Routh & Broadbent, 1983) and retrieval have been found to play a role in remembering (Roediger & Butler, 2011). Moreover, memory has been found not to be a unidirectional process, because retrieval was found to be important not only for remembering but also for forgetting (M. C. Anderson, Bjork & Bjork, 1994). In the context of such findings, two approaches emerged for conceptualising memory. Some theorists argued that memory is best understood in terms of distinct "systems", whereas others preferred thinking about memory in terms of distinct "processes". Although these approaches are not necessarily inconsistent with one another, the distinction between processes and systems has stimulated considerable debate.

The *systems approach* refers to the structure of memory, i.e., different (neural) substrates underlie different systems of (long-term) memory (Foster & Jelicic, 1999), that stand in interaction with each other to enable the "utilization of acquired and retained knowledge" (Schacter & Tulving, 1994, p. 1). A memory system is, thereby, defined by the information that is processed, the brain mechanisms that support it, and the way it operates in relation to other systems (Schacter & Tulving, 1994; Tulving, 1984). It is possible, that different memory systems either work independently, in cooperation or even in competition (Squire & Dede, 2015). In addition, a given task may be solved by a number of different memory systems but some systems would be less optimal than others leading to lower task performance. The *processes approach* refers to the function of memory, i.e., the kind of operations that needs to be performed in any given memory test (Foster & Jelicic, 1999). This approach sees memory as a unitary process in which operations required by a particular test

work along a continuum crossing the borders of different memory systems. Both approaches will be described in more detail in the following two sections.

1.3.1 Memory systems

Schacter and Tulving (1994) distinguished five memory systems: "procedural memory, perceptual representation memory, semantic memory, working memory, and episodic memory" (p. 26). There are several ways to classify these and other systems of memory. One distinction is that between short-term memory (STM) and long-term memory (LTM). While working memory (WM) and the perceptual representation memory (PRS) are considered to be forms of STM[5], procedural memory (PM), semantic memory (SM), and episodic memory (EM) are long-term memory (LTM) processes. While PM and PRS are automatic/unconscious (non-declarative), WM, SM, and EM are open to consciousness and are, therefore, categorised as declarative memory, i.e., it is possible to declare their contents (Squire, 1994). Squire and Dede (2015) considered classical conditioning and non-associative learning as two other forms of non-declarative memory.

PM describes knowledge about learned skills that is expressed when skills need to be performed (Squire & Dede, 2015). It is seen as a behavioural rather than a cognitive system (Schacter & Tulving, 1994). Mochizuki-Kawai (2008) distinguished between motor, perceptual, and cognitive procedures, each being supported by different brain regions. Squire and Dede (2015), additionally, saw habit as a form of procedural memory possibly because of its rigid and repetitive nature.

The PRS deals with the perceptual properties of objects and words, such as their visible structure but not their meaning. It belongs to the non-declarative memory system and

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[5] Baddeley (2012) distinguished short-term memory from working memory based on their respective functions. While short-term memory concerns the storage of information over short periods of time, working memory, in addition, is concerned with its manipulation.

operates at a rather automatic level (Schacter, 1994). Schacter (1994), in a review, found support for three PRS subsystems - a visual-word form system concerning the shape of words without their semantics, the structure-description system concerning the structure of objects, and the auditory word-form system concerning being able to write a spoken word without understanding its meaning.

A multi-component WM model replaced the old view of a unitary system for short-term memory (Baddeley, 2000; Baddeley & Hitch, 1974). It is limited in capacity, and is divided into an attentional unit (central executive) and a storage unit (episodic buffer; Baddeley, 2000; Baddeley & Hitch, 1974). In addition, there are separate units for the temporary storage of language-related (phonological loop), visual and spatial material (visuo-spatial sketchpad) and, possibly, for movement and touch (Baddeley, 2012). The storage systems, thereby, communicate with LTM (Baddeley, 2012).

Tulving (2002) distinguished between SM and EM as forms of LTM. SM is our store for facts and knowledge about the world, which is separated from the personal experiences in which we acquire them (Tulving, 1972). Naming a word when seeing its fragments or a brief image of it, being presented with its definition, or doing a lexical decision task are all considered as tests of SM (Tulving, 1972). In contrast, EM is defined as the storage for personal experiences. It does not only include the event but also its relation to the self (autonoetic consciousness) and context information, such as where and when the event happened. EM develops as the latest of all memory systems, and Tulving (2002) argued that it is unique to humans. It involves *mental time travel*, in which an individual re-experiences a past event again at a later time. The related capacity to imagine the self at a future point of time is called *Episodic Future Thinking* (EFT). Free recall tests that require participants to retrieve information without any aid are considered to be prototypical tests of EM (Roediger, Buckner & McDermott, 1999). According to Tulving (2002), SM and EM are related systems

because EM develops out of SM. In addition, EM is highly dependent on SM in that SM stores the definitions of concepts that need to be accessed in order to relate them to the self and to a place and a time in EM (Binder & Desai, 2011). In this context, it is worth noting that the different theories about memory systems do not all distinguish between different types of declarative memory. For example, Binder and Desai (2011) included EM in their definition of SM. Other authors do not agree with the idea of memory systems and rather argue for memory processes (see Foster & Jelicic, 1999; Tulving, 2002), some of which will now be discussed.

1.3.2 Memory processes

The operations afforded by a specific memory test are often presented in the form of dichotomous principles. Among the first of these principles was the *levels of processing approach* (Craik & Lockhart, 1972), which postulates a difference between shallow (processing of perceptual features of study materials) and deep processing (processing of meaning). The deeper something is processed, the stronger and longer durable is its memory trace. Although considerable evidence supported this distinction (Lockhart & Craik, 1990), several nuances in the literature (e.g., Baddeley, 1978; K. Klein & Saltz, 1976; Morris, Bransford & Franks, 1977) led to revisions and extensions of this theory. For example, Bransford, Franks, Morris and Stein (1979) postulated the *transfer-appropriate processing approach* stating that it is not only the level at which information is processed that determines memory strength but also the overlap in the conditions that prevail at encoding and retrieval, whereby shallow processing produces more durable memory traces than deeper processing under some circumstances (Roediger et al., 1999).

Another distinction is that between *automatic* and *effortful* processes (Hasher & Zacks, 1979). Cognitive processes like attention are limited in capacity (Hasher & Zacks, 1979). Automatic processes operate with minimal attention and, therefore, do not reduce this

capacity. They work despite other cognitive processes, without intention, and their task is to prevent an overload of the system. Effortful processes are guided by intention, and they use up capacity, for instance, when individuals use specific mnemonic techniques for remembering something. Capacity is also decreased by factors such as old age, whereby only effortful but not automatic processes should be affected (Hasher & Zacks, 1979).

Another principle distinguishes between *perceptual* (data-driven) and *conceptual* processes (e.g., Roediger, Weldon & Challis, 1989). Priming tests probe perceptual processes, because they ask participants to focus on perceptual features of the studied materials, whereas conceptual tests necessitate that meaning is processed. Explicit and implicit memory tests are ordered along this distinction. Explicit tests are conceptual tests, because the processed material is available to conscious/active retrieval. Implicit memory is tested with perceptual tests, and as a consequence the information is not open to conscious awareness. However, not all explicit tests are conceptual (e.g., shallow level encoding tasks involve perceptual processing in an explicit task), and not all implicit tests are perceptual (e.g., priming tests of word associations; see Roediger et al., 1999). Buchner and Wippich (2000) argued that a distinction between implicit and explicit memory tests is often just a coincidence of a difference in reliability of tests with explicit memory tests proving more reliable, although this does not necessarily have to be the case. The perceptual-conceptual distinction also underlies the *dual-process theory of recognition memory* with *familiarity* being a perceptual and *recollection* a conceptual process (Mandler, 2008). The two processes *recollection* and *familiarity* are thought to underlie recognition memory judgements (Yonelinas, 2002). Research indicates that Yes/No paradigms are supported more by recollection, whereas forced-choice paradigms seem to benefit more from familiarity and older individuals, who experience a decrease in recollection, therefore, perform worse on Yes/No as opposed to forced-choice paradigms (Bastin & van der Linden, 2003). The

Remember/Know (R/K) procedure is widely used to investigate the processes of familiarity and recollection, and it is seen as an empirical dissociation of the distinction between EM and SM with Remember (R) as retrieval from EM and Know (K) as retrieval from SM (Tulving, 1985). R and K involve different states of conscious awareness. R is the process of recollection in a state of *autonoetic* conscious awareness, i.e., including a sense of self in the remembered event. R responses also include details of when, where, or how something was experienced in addition to the remembered information itself. In contrast, K is a feeling of familiarity in the absence of recollection of such contextual information in a state of *noetic* conscious awareness.[6] It is, however, worth noting that although recollection/familiarity and R/K are similar constructs, they should not be used interchangeably. They are overlapping but they do not map onto each other exactly. When used in the right way, the R/K procedure teases apart memories that largely reflect recollection and others that are largely based on familiarity (Wixted & Mickes, 2010). However, recollection and familiarity are always both involved in R and in K judgements (Wais, Mickes & Wixted, 2008), as has been demonstrated by above chance memory for source information after K judgements in a R/K test. As opposed to the dual-process models, the *signal-detection theory* argues that the R/K paradigm does not test two processes but rather one process with different levels of strength and, therefore, increasing confidence (Banks, 1970; Dunn, 2004; Mandler, 2008; Wixted & Mickes, 2010), and when considered as two processes R reflects high confidence recollection and familiarity, and K indicates low confidence recollection and familiarity (Wixted, 2007). However, more recent research has shown that K responses are also made with high confidence, and R responses are also based on low confidence, and that R and K should rather both be seen as continuous processes (Ingram, Mickes & Wixted, 2012). In addition, when directly comparing confidence ratings and R/K responses, functionally distinct

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[6] It is worth noting that this definition of Know is a bit different from the original definition of SM as a store of general world knowledge (Mandler, 2008).

processes were found (e.g., Parkin & Walter, 1992). Further, research also showed distinct neurological bases for the two processes of R and K (Migo, Mayes & Montaldi, 2012), and a review of behavioural results, such as differing effects of variables like age, divided attention, and modality of the study materials on R and K (Yonelinas, 2002), the availability of context memory only for R responses (Gardiner, Ramponi & Richardson-Klavehn, 1998; Perfect, Mayes, Downes & van Eijk, 1996), and an increase of K responses for a loss of detail memory (Dudukovic & Knowlton, 2006), suggested that the data are represented best by a model of two processes (Brainerd, Gomes & Moran, 2014).

A final important processing distinction is that between *item* and *relational memory* with item memory concerning the memory for single units of material with one meaning, such as single words or pictures (Cohen, Poldrack & Eichenbaum, 1997), and relational memory representing the memory for context information or relations among single items (Davachi, 2006). Whereas item processing refers to the processing of information that distinguishes items from one another, relational processing focusses on the relations among single items (Guynn, Einstein & Hunt, 1992). The roles of relations among study materials and relational and item-specific encoding instructions have been studied extensively in the TD population. For example, when Hunt and Einstein (1981) tested their participants' memory for previously studied word lists, they found that words from related lists, i.e., lists that contained words from the same categories, were better remembered than unrelated words, i.e., lists that contained words from different categories. In addition, item-specific encoding instructions, i.e., rating words for their pleasantness at study, were more beneficial for recalling words from related lists, whereas relational encoding instructions, i.e., sorting words according to their category, improved recall for words from unrelated lists. In another study using pictorial material, Chalfonte and Johnson (1996) asked their participants to study line-drawings presented in different colours and locations in the cells of a grid. At test,

participants recognised individual items, i.e., images, colours, and locations better than their combinations, such as image-colour or image-location. These studies highlight that EM and recollection, i.e., remembering the context of an item presentation, are inherently relational, whereas SM and familiarity used for remembering the items can benefit from item as well as relational information. Thereby, it has yet to be established if item processing without relational processing or the other way around is at all possible (Davachi, 2006).

In conclusion, both system and process theories have stimulated an enormous number of empirical investigations. Critics (e.g., Roediger et al., 1999), however, have argued that both approaches lack clear definitions of what a system or process should be and seem at times to be too simplistic. Moscovitch (1994) suggested a combination of both approaches, which would be more complex and harder to test but would represent reality better. Whether one agrees with these distinctions or not, they provide a useful heuristic to enable a fine-grained analysis of memory in ASD with the advantage of being able to interpret the findings within a theoretical framework. Having set the theoretical frame of research on memory more generally, the thesis now continues with the presentation of empirical findings and the characterisation of memory in ASD.

1.4   Memory in ASD

1.4.1 Empirical findings on memory in ASD

Research investigating memory with reference to the self in ASD points to specific difficulties with EM. After considering studies with regards to self-monitoring, meta-memory, Autobiographical Memory (ABM; memory for past experiences of the self), and EFT (imagining the self in the future), direct comparisons of EM and SM in ASD will follow. Factors influencing EM in ASD will be highlighted, which will be followed by a presentation

of studies on memory for relations between items, and relations among items and their context.

1.4.1.1 Memory with the self in the centre

Studies testing memory for actions indicate a self-monitoring deficit in ASD. Persons with ASD have shown difficulty distinguishing which actions they had performed themselves out of a choice of actions (e.g., saying or thinking a word - Hala, Rasmussen & Henderson, 2005), and whether they themselves or another person carried out an act, such as laying out cards (Russell & Jarrold, 1999), naming pictures (Lind & Bowler, 2009), or performing first aid actions (Maras, Memon, Lambrechts & Bowler, 2013). In addition, ASD participants correctly remembered fewer actions they had performed themselves (Bigham, Boucher, Mayes & Anns, 2010; Russell & Jarrold, 1999 - Exp. 1 & 2; Zalla et al., 2010). By contrast, ASD individuals performed well when encouraged to comment on the task (D. M. Williams & Happé, 2009), or when asked to perform an action with two objects in real life (Hill & Russell, 2002), both of which may have prompted participants' memory. The last study, however, may have been compromised by a ceiling effect. Further, no difficulties in ASD were reported for tasks with fewer social demands, for example, when participants were asked to indicate which square out of a number of squares on the screen they controlled with the computer mouse (Grainger, Williams & Lind, 2014; D. M. Williams & Happé, 2009), suggesting typical levels of agency in the ASD group. Overall, these data suggest that difficulties become apparent when tasks are more demanding, for example, because of the social demands of the tasks, such as taking turns with another person as an advanced social action would lead to difficulties in ASD individuals (e.g., Lind & Bowler, 2009). In conclusion, having difficulties distinguishing between oneself and another person as the executor of an action indicates a self-monitoring deficit in ASD. Another factor that may play

a role in these difficulties is meta-memory - the awareness of ones' own memories – which will be considered next.

Wojcik, Moulin and Souchay (2013) found indications of compromised meta-memory for EM in ASD. The authors asked children to judge how likely it was that they would later remember the second word of a pair after they had studied a list of word pairs. ASD, as opposed to TD, children underestimated their later memory, as they remembered similar numbers of items that they had previously indicated they would or would not remember, whereas TD children remembered more items they previously indicated as likely that they would remember them as opposed to items that they had rated as unlikely that they would remember them. The authors suspected difficulties relating the cue word to contextual information in ASD, and a lack of contextual details may have made ASD individuals unsure about their judgements. A marginally lower Verbal IQ (VIQ) in the ASD group, however, asks to interpret the results with caution.

After having established that ASD individuals find it difficult to distinguish between themselves and others as the executor of an action and to reflect about their memories, the question arises how well they remember personal experiences from the past (ABM). The answer is that ASD participants more often experienced problems in reporting ABMs (Crane, Pring, Jukes & Goddard, 2012; Chaput et al., 2013; Goddard, Dritschel, Robinson, & Howlin, 2014b), they needed more prompts to produce memories (Goddard et al., 2014b), took longer for their reports when timed (Crane, Goddard & Pring, 2011; Crane et al., 2012; Goddard, Howlin, Dritschel & Patel, 2007), their reports were less accurate when checked against parent reports (Bruck, London, Landa & Goodman, 2007), and they were more factual (Chaput et al., 2013). Persons with ASD also extracted less meaning from past events for the future (Crane, Goddard & Pring, 2010), they reported fewer specific memories (Bruck et al.,

2007; Crane et al., 2010; 2011; 2012; Goddard et al., 2014b; Goddard, Dritschel & Howlin, 2014a; Goddard et al., 2007), with fewer EM details (Adler, Nadler, Eviatar & Shamay-Tsoory, 2010; Crane & Goddard, 2008; Goddard et al., 2014b; S. B. Klein, Chan, & Loftus, 1999; Kristen, Rossmann & Sodian, 2014; Maister, Simons & Plaisted-Grant, 2013; Tanweer, Rathbone & Souchay, 2010), and they stated more general gist-like memories (Crane et al., 2011; 2012; Goddard et al., 2014b; Maister et al., 2013) compared to TD participants. Both groups, however, reported similar numbers of SM details (Adler et al., 2010; S. B. Klein et al., 1999; Kristen et al., 2014). Finally, unlike TD individuals, ASD participants did not show better ABM for more recent times (Bon et al., 2013; Crane & Goddard, 2008; Goddard et al., 2014a), and they sometimes reported fewer remote memories (Goddard et al., 2014a & b). A recent study suggested that poor EFs may play a role in reduced ABM in ASD because only ASD children with poor set shifting abilities reported fewer episodic details, whereas ASD children with good set shifting abilities performed similarly to TD children (Maister et al., 2013). EFs may also play a role when ASD participants show reduced semantic ABM (Goddard et al., 2014b). Not only did ASD children included in this study show reduced set shifting compared to TD individuals, set shifting abilities were also found to be a significant predictor for the number of semantic ABMs, suggesting that ABM difficulties may at least in part be corollary of executive dysfunction rather than memory problems per se. Finally, it is worth noting that in some of the studies presented above groups were not matched in terms of age (e.g., Goddard et al., 2007) or IQ (e.g., Adler et al., 2010; Bon et al., 2013; Bruck et al., 2007) and results should, therefore, be interpreted with caution. In conclusion, studies on ABM show that ASD individuals find it difficult to remember information about their personal past. The question arises if imagining the self in a future point of time (EFT) may also be difficult for them.

Indeed, studies investigating EFT found imagined future events to be less specific in ASD (Lind, Bowler & Raber, 2014a). ASD participants reported fewer episodic details (Terrett et al., 2013). In addition, descriptions of ASD children were judged as less likely by their parents (Lind et al., 2014a) compared to events reported by TD children that were judged by their own parents. Further, ASD participants judged the quality of their imagined future events as lower compared to TD participants. They reported a lower sense of presence, lower salience of the reports, and more fragmentation (Lind, Williams, Bowler & Peel, 2014b). Hanson and Atance (2014) reported difficulties in ASD with EFT involving the imaginary preparation of future trips. However, groups were not matched on IQ and age in this study and, therefore, results should be interpreted with caution. One study found no between-group differences in EFT when participants were asked to complete sentences regarding future events (Crane, Lind & Bowler, 2013), which may have been an easier task for the ASD individuals because of the support the sentence parts provided than producing thoughts based on a cue word in an interview situation involving another person (Lind et al., 2014a; Terrett et al., 2013). The studies considered so far point to specific difficulties in ASD with EM - the memory for personal experiences. Only few of the discussed studies also examined SM. Therefore, systematic comparisons of EM and SM in ASD will be discussed next.

1.4.1.2   Episodic versus semantic memory in ASD

EM and SM were both found to depend upon the Medial Temporal Lobe (MTL) of the brain, which is a structure including the hippocampus, perirhinal, parahippocampal, and entorhinal brain regions (Eichenbaum, Yonelinas & Ranganath, 2007). Whereas the perirhinal cortex was found particularly responsible for SM, the hippocampus was found especially involved in EM (Eichenbaum et al., 2007). The Prefrontal Cortex (PFC) is also thought to play a role in EM (Tulving, 1989). The R/K recognition memory procedure has been used frequently to

assess EM and SM with R measuring EM and K responses indicating SM. Because it is one of the procedures used in the empirical studies of this thesis, it is useful to examine previous studies that have used this procedure in ASD in some detail. An overview of R/K studies in ASD is presented in Table 1.1, and they will be described in what follows.

Table 1.1

Studies using the R/K recognition procedure comparing ASD and TD participants.

Participant characteristics		Materials and procedures		Results		Cohen's *d*	
ASD	TD			ASD	TD		
M (*SD*)	*M* (*SD*)			*M* (*SD*)	*M* (*SD*)		
Bowler, Gardiner & Grice (2000a)							
N 16 (13 m)	15 (14 m)						
age 30.9 (6.3)	31.1 (5.6)	- words	**H-FA[c] overall**	0.47 (0.15)	0.48 (0.16)	**H-FA[c] overall**	0.06
VIQ[a] 93 (16.6)	97 (14.4)	- high- & low-frequency	**H-FA[c] R**	0.30 (0.18)	0.40 (0.14)	**H-FA[c] R**	**0.62**
PIQ[b] 89 (14.1)	90 (11.8)	- R/K procedure	**H-FA[c] K**	0.17 (0.15)	0.08 (0.08)	**H-FA[c] K**	*0.75*
Bowler & Ring (in preparation)							
N 30 (23 m)	28 (21 m)						
age 42.9 (11.9)	43.3 (14.1)	- words	**H-FA[c] overall**	0.45 (0.25)	0.62 (0.24)	**H-FA[c] overall**	0.69
VIQ[a] 111 (17.0)	114 (14.8)	- high- & low-frequency	**H-FA[c] R**	0.29 (0.25)	0.47 (0.28)	**H-FA[c] R**	**0.68**
PIQ[b] 107 (18.4)	109 (12.7)	- R/K procedure	**H-FA[c] K**	0.16 (0.18)	0.15 (0.16)	**H-FA[c] K**	0.06
Massand (2011) PhD thesis - Exp. 2							
N 23 (17 m)	22 (17 m)						
age 37.4 (12.8)	42.2 (11.6)	- words	**H-FA[c] overall**	0.57 (0.31)	0.66 (0.24)	**H-FA[c] overall**	0.33
VIQ[a] 107 (13)	110 (16)	- high- & low-frequency	**H-FA[c] R**	0.37 (0.27)	0.55 (0.23)	**H-FA[c] R**	**0.70**
PIQ[b] 106 (17)	106 (18)	- R/K procedure	**H-FA[c] K**	0.21 (0.22)	0.11 (0.12)	**H-FA[c] K**	*0.55*

Participant characteristics		Materials and procedures		Results		Cohen's *d*	
ASD *M (SD)*	**TD** *M (SD)*			**ASD** *M (SD)*	**TD** *M (SD)*		
Massand (2011) PhD thesis - Exp. 4							
N 12 (9 m)	12 (11 m)						
age 40.0 (11.4)	40.1 (11.1)	- kaleidoscope images	**H-FA[c] overall**	0.44 (0.21)	0.60 (0.21)	**H-FA[c] overall**	0.76
VIQ[a] 110 (14)	112 (19)	- R/K/New procedure	**H-FA[c] R**	0.26 (0.26)	0.51 (0.19)	**H-FA[c] R**	**1.10**
PIQ[b] 112 (16)	105 (18)		**H-FA[c] K**	0.18 (0.13)	0.09 (0.07)	**H-FA[c] K**	0.86
		- R justifications	**JR[d]**	0.35 (0.09)	0.57 (0.05)	**JR[d]**	3.02
Tanweer, Rathbone & Souchay (2010)							
N 11 (9 m)	15 (4 m)						
age 34.1 (11.1)	32.7 (9.5)	- autobiographical memories	**overall**	0.66 (0.09)	0.74 (0.03)	**overall**	1.19
VIQ[a] 110 (11.3)	109 (11.0)	- three lifetime periods	**R**	0.45 (0.10)	0.60 (0.05)	**R**	**1.90**
PIQ[b] 113 (10.4)	109 (10.1)	- R/K/Guess procedure	**K**	0.21 (0.05)	0.13 (0.04)	**K**	*1.77*
		- R justifications	**JR[d]**	0.35 (0.09)	0.57 (0.05)	**JR[d]**	3.02
Manipulations							
Bowler, Gardiner & Gaigg (2007) - Exp. 1							
N 18 (14 m)	18 (15 m)						
age 33 (10.7)	34 (8.7)	- words	**H-FA[c] ov full A[e]**	0.57 (0.19)	0.64 (0.21)	**H-FA[c] ov full A[e]**	0.35
VIQ[a] 102 (16.9)	102 (15.0)	- full vs divided attention	**H-FA[c] R full A[e]**	0.39 (0.21)	0.51 (0.22)	**H-FA[c] R full A[e]**	**0.56**
PIQ[b] 94 (18.6)	101 (12.9)	- R/K procedure	**H-FA[c] K full A[e]**	0.16 (0.11)	0.09 (0.11)	**H-FA[c] K full A[e]**	0.64
			H-FA[c] ov div A[f]	0.23 (0.12)	0.32 (0.18)	**H-FA[c] ov div A[f]**	0.59
			H-FA[c] R div A[f]	0.11 (0.08)	0.20 (0.18)	**H-FA[c] R div A[f]**	**0.65**
			H-FA[c] K div A[f]	0.09 (0.09)	0.07 (0.11)	**H-FA[c] K div A[f]**	0.20

Participant characteristics		Materials and		Results		Cohen's *d*	
ASD	**TD**	**procedures**		**ASD**	**TD**		
M (*SD*)	*M* (*SD*)			*M* (*SD*)	*M* (*SD*)		
Bowler et al. (2007) - Exp. 2							
N 24 (18 m)	24 (17 m)						
age 33 (11.5)	33 (10.4)	- words	**H-FA[c] ov visual**	0.26 (0.14)	0.23 (0.17)	**H-FA[c] ov visual**	0.19
VIQ[a] 103 (14.3)	103 (12.7)	- perceptual instruction	**H-FA[c] R visual**	0.08 (0.09)	0.11 (0.10)	**H-FA[c] R visual**	0.32
PIQ[b] 103 (18.8)	104 (13.1)	- verbal vs visual	**H-FA[c] K visual**	0.18 (0.13)	0.12 (0.14)	**H-FA[c] K visual**	0.44
		presentation	**H-FA[c] ov verbal**	0.17 (0.15)	0.20 (0.13)	**H-FA[c] ov verbal**	0.21
		- R/K procedure	**H-FA[c] R verbal**	0.09 (0.06)	0.09 (0.09)	**H-FA[c] R verbal**	0
			H-FA[c] K verbal	0.07 (0.13)	0.11 (0.09)	**H-FA[c] K verbal**	0.36
Bowler et al. (2007) - Exp. 3							
N 16	16						
age 35 (10.5)	35 (8.8)	- words	**H-FA[c] ov once**	0.54 (0.19)	0.51 (0.23)	**H-FA[c] ov once**	0.14
VIQ[a] 100 (13.0)	102 (12.1)	- lexical decision task	**H-FA[c] R once**	0.32 (0.22)	0.32 (0.25)	**H-FA[c] R once**	0
PIQ[b] 99 (16.0)	101 (10.4)	- repeated presentation	**H-FA[c] K once**	0.22 (0.18)	0.19 (0.14)	**H-FA[c] K once**	0.19
		- R/K procedure	**H-FA[c] ov thrice**	0.73 (0.19)	0.79 (0.13)	**H-FA[c] ov thrice**	0.37
			H-FA[c] R thrice	0.48 (0.25)	0.55 (0.14)	**H-FA[c] R thrice**	0.35
			H-FA[c] K thrice	0.25 (0.22)	0.25 (0.11)	**H-FA[c] K thrice**	0
Souchay, Wojcik, Williams, Crathern & Clarke (2013) - Exp. 1							
N 19 (16 m)	19 (14 m)						
age 13.2 (2.7)	14.2 (2.4)	- pictures & verbal labels	**Hits-FA overall**	0.64 (0.14)	0.62 (0.15)	**Hits-FA overall**	0.17
VIQ[a] 115 (16.5)	123 (12.6)	- colour, gender of	**Hits R**	0.11 (0.13)	0.23 (0.19)	**Hits R**	**0.74**
PIQ[b] 109 (14.9)	108 (13.9)	speaker	**Hits K**	0.89 (0.13)	0.77 (0.19)	**Hits K**	0.70
		- R/K/New procedure					
		with words					

Participant characteristics			Materials and procedures		Results			Cohen's *d*	
	ASD	**TD**				**ASD**	**TD**		
	M (*SD*)	*M* (*SD*)				*M* (*SD*)	*M* (*SD*)		
Souchay et al. (2013) - Exp. 2									
N	19 (16 m)	19 (14 m)							
	see Exp. 1	see Exp. 1							
age	13.2 (2.7)	14.2 (2.4)	- words		**Hits-FA overall**	0.55 (0.23)	0.58 (0.18)	**Hits-FA overall**	0.10
VIQ[a]	115 (16.5)	123 (12.6)	- R/K/New procedure		**Hits R**	0.10 (0.15)	0.13 (0.20)	**Hits R**	0.17
PIQ[b]	109 (14.9)	108 (13.9)	- temporal order in list		**Hits K**	0.90 (0.15)	0.87 (0.20)	**Hits K**	0.17
Souchay et al. (2013) - Exp. 3									
N	19 (16 m)	19 (14 m)							
	see Exp. 1	see Exp. 1							
age	13.2 (2.7)	14.2 (2.4)	- four words in		**Hits-FA overall**	0.44 (0.26)	0.58 (0.17)	**Hits-FA overall**	0.66
VIQ[a]	115 (16.5)	123 (12.6)	quadrants of a box		**Hits R**	0.12 (0.25)	0.12 (0.15)	**Hits R**	0
PIQ[b]	109 (14.9)	108 (13.9)	- R/K/New procedure		**Hits K**	0.88 (0.25)	0.88 (0.15)	**Hits K**	0.01
Memory illusions									
Bowler, Gardiner, Grice & Saavalainen (2000b)									
N	10	10							
age	28.5 (8.6)	26.1 (9.0)	-words		**H-FA**[c] **ov old**	0.68 (0.21)	0.79 (0.15)	**H-FA**[c] **ov old**	0.60
VIQ[a]	89 (9.7)	93 (15.4)	-old, new unrelated,		**H-FA**[c] **R old**	0.51 (0.24)	0.72 (0.16)	**H-FA**[c] **R old**	**1.03**
PIQ[b]	83 (8.9)	89 (18.1)	new related words at test		**H-FA**[c] **K old**	0.17 (0.15)	0.07 (0.09)	**H-FA**[c] **K old**	0.81
			-R/K procedure		**H-FA**[c] **ov new rel**	0.28 (0.20)	0.46 (0.26)	**H-FA**[c] **ov new rel**	0.78
					H-FA[c] **R new rel**	0.26 (0.19)	0.43 (0.25)	**H-FA**[c] **R new rel**	**0.77**
					H-FA[c] **K new rel**	0.01 (0.03)	0.03 (0.05)	**H-FA**[c] **K new rel**	0.49

Participant characteristics		Materials and procedures		Results		Cohen's *d*	
ASD *M* (*SD*)	**TD** *M* (*SD*)			**ASD** *M* (*SD*)	**TD** *M* (*SD*)		
Massand (2011) PhD thesis - Exp. 3							
N 14 (12 m)	16 (14 m)						
age 40.2 (14.4)	36.3 (12.3)	-words	**H-FA**[c] **ov old**	0.59 (0.18)	0.65 (0.16)	**H-FA**[c] **ov old**	0.35
VIQ[a] 115 (11)	112 (17)	-R/K procedure	**H-FA**[c] **R old**	0.42 (0.22)	0.47 (0.18)	**H-FA**[c] **R old**	0.25
PIQ[b] 112 (14)	112 (16)		**H-FA**[c] **K old**	0.17 (0.09)	0.18 (0.15)	**H-FA**[c] **K old**	0.08
			H-FA[c] **ov new rel**	0.22 (0.12)	0.21 (0.13)	**H-FA**[c] **ov new rel**	0.08
			H-FA[c] **R new rel**	0.12 (0.10)	0.10 (0.09)	**H-FA**[c] **R new rel**	0.21
			H-FA[c] **K new rel**	0.10 (0.10)	0.10 (0.08)	**H-FA**[c] **K new rel**	0
Meyer, Gardiner & Bowler (2014)							
N 16 (12 m)	16 (10 m)						
age 36.5 (11.7)	37.7 (13.9)	-words under directed	**H-FA**[c] **ov TBL**[g]	0.60 (0.27)	0.77 (0.16)	**H-FA**[c] **ov TBL**[g]	0.77
VIQ[a] 105 (14.6)	105 (14.1)	forgetting instructions	**H-FA**[c] **R TBL**[g]	0.41 (0.31)	0.56 (0.22)	**H-FA**[c] **R TBL**[g]	0.56
PIQ[b] 103 (18.8)	106 (12.5)	-R/K procedure	**H-FA**[c] **K TBL**[g]	0.20 (0.16)	0.21 (0.16)	**H-FA K TBL**[g]	0.06
			H-FA[c] **ov TBF**[h]	0.43 (0.24)	0.44 (0.23)	**H-FA**[c] **ov TBF**[h]	0.04
			H-FA[c] **R TBF**[h]	0.22 (0.18)	0.18 (0.14)	**H-FA**[c] **R TBF**[h]	0.26
			H-FA[c] **K TBF**[h]	0.21 (0.13)	0.26 (0.16)	**H-FA**[c] **K TBF**[h]	0.35

Participant characteristics		Materials and		Results		Cohen's *d*	
ASD	**TD**	**procedures**		**ASD**	**TD**		
M (*SD*)	*M* (*SD*)			*M* (*SD*)	*M* (*SD*)		

Relational

Gaigg, Bowler, Ecker, Calvo-Merino & Murphy (2015)

	ASD	TD	Materials and procedures	Results label	ASD	TD	Cohen's d label	Cohen's d
N	13 (12 m)	12 (11 m)						
age	35.6 (10.3)	35.5 (10.5)	-word triads	**H-FA^c overall**	0.27 (0.15)	0.28 (0.10)	**H-FA^c overall**	0.11
VIQ^a	106 (12.4)	113 (15.2)	-R/K/Guess procedure	**H-FA^c R**	0.26 (0.15)	0.45 (0.17)	**H-FA^c R**	**1.19**
PIQ^b	107 (17.6)	108 (13.8)		**H-FA^c K**	0.26 (0.15)	0.22 (0.05)	**H-FA^c K**	0.36
				H-FA^c Guess	0.28 (0.15)	0.17 (0.07)	**H-FA^c Guess**	0.94

Note. [a]VIQ - Verbal IQ. [b]PIQ - Performance IQ. [c]H-FA - corrected recognition rates - Hit rates (H) minus False Alarm (FA) rates. [d]JR - Remember justifications. [e]full A - full attention. [f]div A - divided attention. [g]TBL - to be learned. [h]TBF - to be forgotten. Effect sizes in bold represent between-group differences in R responses, where TD participants performed significantly higher than ASD participants. Effect sizes in italics represent between-group differences in K responses with significantly higher performance in the ASD compared to the TD group.

Findings generally indicate reduced EM but intact SM in ASD. Using the R/K procedure, ASD individuals have shown reduced R rates compared to TD participants for words (Bowler, Gardiner & Gaigg, 2007 Exp. 1; Bowler, Gardiner & Grice, 2000a; Bowler, Gardiner, Grice & Saavalainen, 2000b; Bowler & Ring, in preparation; Massand, 2011 Exp. 2; Meyer, Gardiner & Bowler, 2014), word triplets (Gaigg, Bowler, Ecker, Calvo-Merino & Murphy, 2015), pictures (Souchay, Wojcik, Williams, Crathern & Clarke, 2013 Exp. 1), non-nameable kaleidoscope images (Massand, 2011 Exp. 4), and ABMs (Tanweer et al., 2010). Sometimes reduced R rates were compensated by increased K (Bowler et al., 2000a; Massand, 2011 Exp. 2; Tanweer et al., 2010) or Guess rates (Gaigg et al., 2015) in ASD. When looking at the effect of instructions, between-group differences were found for perceptual encoding instructions in that they reduced K responses only in ASD individuals. The authors argued that TD individuals may have been able to overcome potential difficulties by other strategies that may have not been available to ASD individuals (Bowler et al., 2007 Exp. 2). Similarly, instructions to remember materials rather than to forget them in a directed forgetting paradigm had differential effects on ASD and TD groups. Whereas ASD participants remembered fewer words they were asked to remember compared to TD participants, both groups reported a similar number of words they were asked to forget. The authors interpreted this observation as resulting from less effective encoding strategies in ASD (Meyer et al., 2014). When testing the effect of various manipulations on rates of R and K, ASD and TD groups were similarly affected by divided attention (Bowler et al., 2007 Exp. 1), repeated presentations (Bowler et al., 2007 Exp. 3), the position of a phoneme change in a word (Bowler et al., 2007 Exp. 3), forgetting instructions in a directed forgetting paradigm (Meyer et al., 2014), as well as intentional encoding instructions (Souchay et al., 2013 Exp. 1). These results, and studies inspecting justifications for R responses finding no significant differences between groups (Bowler et al., 2000b; Souchay et al., 2013 Exp. 1), indicate a

similar quality of R and K responses in ASD and TD participants. Whereas most studies have shown overall levels of corrected recognition rates that were not significantly different between the two groups, the effect sizes for the between-group differences were medium to large (e.g., Bowler et al., 2000b; Massand, 2011 Exp. 2 & 4), suggesting that sample sizes might have been too small to detect more subtle differences between groups. Two studies have found reduced overall recognition memory for the ASD group (Bowler & Ring, in preparation; Tanweer et al., 2010). Bowler and Ring (in preparation) had tested a large sample (N_{ASD} = 30, N_{TD} = 28) compared to other studies and, therefore, had more statistical power to detect smaller differences between groups. Moreover, Tanweer et al. (2010) had used ABMs as materials, which might have been particularly difficult for ASD individuals, given the evidence set out in the previous section (1.4.1.1). Three studies did not find any differences between groups in R rates using words (Massand, 2011 Exp. 3; Souchay et al., 2013 Exp. 2 & 3). The lack of a between-group difference in R responses in Souchay et al. (2013 Exp. 2 & 3) may have been caused by the fact that the same participants took part in all three experiments within the same testing session creating order effects. Specifically, low R rates in both groups as well as a considerable drop in TD individuals' R responses in experiments two and three suggested that group differences may have been masked by participants' inattention or exhaustion in later experiments. Similar R rates in both groups in Massand (2011 Exp. 3) may have been caused by a reduced performance of the TD group and/or an increased performance of the ASD group, especially for false targets in comparison to other studies of this kind (e.g., Bowler et al., 2000b), masking a between-group difference.

Three studies have investigated brain responses related to R/K judgements. When inspecting Event-related Potentials (ERPs), which are responses in the Electroencephalogram (EEG) that are measured after an event of interest, such as a stimulus presentation on-screen, researchers repeatedly found no between-group differences relating to R but differences in

time windows and topographical distribution relating to K responses (Massand, 2011 Exp. 2 & 4), which may have resulted from increased Guess rates within K responses in the ASD group (Massand, 2011 Exp. 2). Differential regional brain activation for ASD and TD participants was also found when using functional Magnetic Resonance Imaging (fMRI) during a R/K/Guess procedure (Gaigg et al., 2015). Whereas ASD individuals showed no difference in activation between R and K, signal changes in the middle and inferior frontal gyrus were larger for R compared to K for the TD group. These studies suggest that reduced EM in ASD may be caused by a different neural activity underlying SM.

Overall the studies considered in this chapter point to specific behavioural difficulties with EM in ASD, leaving SM mostly intact. Therefore, EM will be considered in greater detail in the next two sections.

1.4.1.3   Factors influencing episodic memory in ASD

EM difficulties in ASD are likely related to three factors that have frequently been supported in memory research in ASD, which are the reduced use of organisational strategies, the diminished spontaneous use of material-inherent relatedness, and the benefit from task support, each of which will be considered in more detail below.

Reduced organisation of study materials in ASD has been found in terms of lower semantic clustering as well as random free recall reports. ASD participants clustered words less into their categories in free recall tests (Bowler, Gaigg & Gardiner, 2010; Gaigg, Gardiner & Bowler, 2008; Minshew & Goldstein, 1993), and their clustering reached a plateau, while TD individuals' clustering increased further (Sumiyoshi, Kawakubo, Suga, Sumiyoshi & Kasai, 2011). In addition, ASD individuals' oral and written free recall outputs were more idiosyncratic than TD individuals' recalls (Bowler, Gaigg & Gardiner, 2008a), and whilst the subjective organisation of TD participants' memories both increased and became more similar over the 16 trials of the task in which the same words were presented

repeatedly, ASD individuals' recalls, although increasing over trials, did not become more similar. ASD individuals' recall of an unrelated word list was also reported as significantly more re-organised (Maister & Plaisted-Grant, 2011). In terms of the typical serial position curve with primacy (remembering more items from the beginning of a list) and recency effects (remembering more items from the end of a list), ASD individuals showed a decreased primacy but an increased recency effect in the free recall of pictures (Renner, Klinger & Klinger, 2000). In addition, while TD individuals' primacy effect improved in the free recall of words over a series of trials, ASD participants showed a typical primacy effect only in Trial 1, which then reached a plateau over the next few trials (Bowler, Limoges & Mottron, 2009), indicating a different organisation of study materials in ASD participants for repeated presentations of the same word list.

In addition to a different organisation of the study materials, individuals with ASD do not spontaneously use the semantic or syntactic structure of materials to aid their recall. While Intellectually Disabled (ID; Hermelin & O'Connor, 1967) as well as TD children (Ramondo & Milech, 1984) benefitted from the syntactic structure of sentences, ASD children showed similar recall for sentences as for random word strings. Similarly, ASD participants performed worse on semantically (Boucher & Warrington, 1976; Bowler, Matthews & Gardiner, 1997; Bowler, Gaigg & Gardiner, 2008b; Lopez & Leekam, 2003; Maister et al., 2013; Minshew & Goldstein, 2001; Minshew, Goldstein & Siegel, 1997; Tager-Flusberg, 1991) and phonologically related (B. J. Smith, Gardiner & Bowler, 2007) as well as hierarchically organised word lists (Bowler, Gaigg & Gardiner, 2009), but they performed like TD individuals in the free recall of lists of unrelated words. Less use of semantic relatedness of materials in ASD was also reflected in the recall of fewer categories especially for categories with fewer items (Bowler et al., 2009; Gaigg et al., 2008; Maister et al., 2013), as well as lower free recall of details in a story (O'Shea, Fein, Cillessen, Klin &

Schultz, 2005). ASD participants also benefitted less from training in the use of relations among words (B. J. Smith et al., 2007).

The studies just described point to difficulties in spontaneously using information that is inherent in the study materials to support retrieval (particularly free recall) in ASD. Difficulties in memory in ASD become less pronounced when additional support is provided at test. This observation led Bowler et al. (1997) to develop the *Task Support Hypothesis* (TSH) for ASD to describe the phenomenon whereby ASD individuals seem to show particular difficulties with free recall tasks, so called unsupported tests, because they do not provide cues or guidance to help recall, but almost intact performance on cued recall or recognition tests, so called supported tests, that either give a choice of possible answers or cues to the correct answer. Research supporting the TSH found lower free recall of lists of single words (Bowler et al., 1997), word pairs (Bowler et al., 2008b), story details (O'Shea et al., 2005), the gender of the voice or the location on the screen a word (Bowler, Gaigg & Gardiner, 2015; Bowler, Gardiner & Berthollier, 2004) or a dot (Bowler, Poirier, Martin & Gaigg, 2016) was presented in at study. Between-group differences, however, disappeared when using cued recall (Bowler et al., 1997; Bowler et al., 2016) and (four-possibility) recognition test procedures (Bowler et al., 2004; 2008b; 2015; Cooper et al., 2015; O'Shea et al., 2005). In a free recall test, but not following questions, ASD individuals falsely attributed more actions that they had performed themselves to the experimenter (Maras et al., 2013). ASD participants also better distinguished between actions performed by themselves compared to those performed by another person, when they and the other person were holding a different coloured block while reading out a word (Farrant, Blades & Boucher, 1998; Hala et al., 2005). Finally, semantic clustering was also found to improve when a cued rather than a free recall test was used (Phelan, Filliter & Johnson, 2011). Research showed that support at encoding is also beneficial for ASD memory. Without support, ASD compared

to TD individuals remembered fewer categories (Gaigg et al., 2008). However, when participants were instructed to sort words into their different categories at encoding (relational encoding) ASD and TD individuals performed without difference. Similarly, B. J. Smith et al. (2007) found significantly lower free recall of word lists in ASD compared to TD participants, but when training groups in mnemonic strategies, recall increased slightly in ASD individuals.

These findings overall indicate that support at retrieval as well as encoding is beneficial for ASD memory. Another open question in ASD research relates to the processes of encoding and retrieval, and whether memory difficulties are caused by problems in memory retrieval, or if an encoding deficit has a knock-on effect on retrieval, or if both are problematic. A recent study claimed that problems at the stage of encoding in ASD, at least in part, led to later difficulties at retrieval (Gaigg et al., 2015). That is because ASD participants showed particular difficulties in R retrieval and only R retrieval was sensitive to the relational nature of the to-be-remembered triplets (i.e., varying degrees of semantic relatedness). In addition, the authors found similar brain activation for R and K rates in ASD as opposed to increased encoding activation for R compared to K in TD individuals.

The results described in this section point to specific difficulties in relational processing in ASD (Bowler, Gaigg & Lind, 2011) and, therefore, memory for relations between items and among items and their context in ASD will be considered next.

1.4.1.4 Memory for relations between items and among items and their context

Item and relational memory have been reported to have distinct neural substrates within the MTL with the perirhinal cortex processing item information, the parahippocampal cortex processing context information and the signal of the hippocampus being related to relational binding of individual items and their context (Davachi, 2006; L. R. Howard, Kumaran,

Ólafsdóttir & Spiers, 2011). Recent research suggested an additional involvement of the PFC as well as the parietal cortex in item as well as relational memory (Ackerman & Courtney, 2012).

Memory for relational material can be distinguished into memory for different types of relations. There are relations between items or among items and their context. In addition, Halford (1992) described different types of relations in his *taxonomy of cognitive development*, that increase in complexity starting with the processing of individual items as *unary relations*, the processing of pairs of items called *binary relations*, and the processing of the relations among more than two items starting with *ternary relations* - the processing of relations among triplets of items. Keeping this taxonomy in mind, the thesis will start with considering memory for pairs of items, followed by memory for items and their context.

When participants were asked to associate pairs of items (paired associate learning) and their memory was tested with a cued recall test, most studies found no differences between groups using unrelated (Ambery, Russell, Perry, Morris & Murphy, 2006; Boucher & Warrington, 1976; Brown, Aczel, Jiménez, Kaufman & Plaisted Grant, 2010; Minshew et al., 1997; Salmond et al., 2005; D. L. Williams, Goldstein & Minshew, 2005), as well as related word pairs (Gardiner, Bowler & Grice, 2003), unrelated picture pairs (Morton-Evans & Hensley, 1978), and sound-symbol pairs (D. L. Williams, Goldstein & Minshew, 2006). Two studies reported differences in verbal as well as visual paired associate learning when groups were not matched on IQ (Brown et al., 2010; Salmanian, Tehrani-Doost, Ghanbari-Motlagh & Shahrivar, 2012). Since paired associate learning was found to be related to IQ (Estes & Huizinga, 1974; Uttl, Graf & Richter, 2002), results of these studies need to be interpreted with caution. Most of the studies referred to above have used standardised tasks, such as the *Cambridge Neuropsychological Test Automated Battery* (CANTAB; Salmanian et al., 2012), the *Wechsler Memory Scale* (WMS; e.g., Ambery et al., 2006; D. L. Williams et

al., 2005), or the *Children's Memory Scale* (CMS; e.g., Salmond et al., 2005), where participants are generally presented with eight pairs of items. It is possible that these tasks are too easy to capture any slight difficulties that ASD individuals might show, which was suggested by the finding of a ceiling effect in the WMS (Uttl et al., 2002). Another reason for null-effects may have been the small sample sizes of some of the studies (e.g., Boucher & Warrington, 1976, $N = 12$ in each group; Gardiner et al., 2003, $N = 10$ in each group; Morton-Evans & Hensley, 1978, $N = 5$ in each group) causing statistical power to be too low to detect differences between groups, which was supported by the finding of difficulties when large samples were used (e.g., Minshew & Goldstein, 2001, $N_{ASD} = 52$, $N_{TD} = 40$). Between-group differences were found to be of more subtle nature as higher False Alarm (FA) rates in ASD participants for a test of word pairs (Gardiner et al., 2003) showed. Difficulties in paired associate learning in ASD were also found when unusual combinations were tested, such as related picture-sound pairs (Morton-Evans & Hensley, 1978), or face-house pairs (Gaigg, Rogers & Bowler, 2012), or when more taxing tasks were used such as hidden-link tasks (Gaigg et al., 2012). In such a task, autistic adults were tested with two lists of face-house pairings (Gaigg et al., 2012). In the second list, the houses from List 1 were re-paired with new faces, and at the final test participants were presented with the two faces from each list without the houses, intermixed with other unpaired faces, and participants were asked to pick the two related faces. Only half of the ASD participants reached criterion during list learning and the ASD group overall performed much worse than TD individuals on the final test. In a second experiment, that did not contain a social component, participants were tested with the same procedure but with unrelated object pairs. At test, participants were presented with the two objects that were linked because of an earlier presentation with a third object, intermixed with other unrelated objects. The third object was not presented. Again, ASD participants showed slower learning and lower performance on the final test compared to TD individuals.

Gaigg et al. (2012) interpreted this finding as showing poorer flexibility in combining and re-combining elements in EM in ASD.

When looking at memory for the context of item presentation, ASD individuals showed difficulties in remembering the locations for words or pictures on the computer screen (Bowler, Gaigg & Gardiner, 2014; Bowler et al., 2004; Cooper et al., 2015; Semino, Ring, Bowler & Gaigg, in preparation), the gender of the voice that spoke a word at study (Bowler et al., 2004), the face of a person, as well as the folder they were holding, in a video telling a story (O'Shea et al., 2005), the colours images were presented in at study (Massand & Bowler, 2015), and the temporal order of the presentation of words (Bennetto, Pennington & Rogers, 1996; Poirier, Martin, Gaigg & Bowler, 2011), pictures (Bennetto et al., 1996), digits (Poirier et al., 2011), everyday objects (Bigham et al., 2010; Ni Chuileann & Quigley, 2013), locations of dots in a grid (Bowler et al., 2016), and famous characters in history (Gaigg, Bowler & Gardiner, 2014). More intrusion errors on the second list of the *California Verbal Learning Test* (CVLT) were reported for ASD individuals, indicating difficulties to remember which list a word was previously presented in (Bennetto et al., 1996; Minshew & Goldstein, 1993). In some studies, between-group differences for context memory may have been masked by order effects (Souchay et al., 2013), small sample sizes (Maister & Plaisted-Grant, 2011, $N = 15$ in each group), or ceiling effects (Gras-Vincendon, Mottron, Salamé, Bursztejn & Danion, 2007), and results should, therefore, be interpreted with caution. In addition, no difficulties were found in simpler tasks such as remembering a background for an item (Lind et al., 2014a). It is possible that participants mentally merged item and background into a single image in this study. Regarding temporal order memory, inconsistent results may have occurred because groups were matched on VIQ, and digit span as a test of temporal order memory is part of VIQ. Matching on VIQ may, therefore, have obscured the effects researchers were interested in (e.g., Bowler et al., 2015; Gras-Vincendon et al., 2007;

Maister & Plaisted-Grant, 2011; Souchay et al., 2013). An alternative was presented by Bowler et al. (2016) and Poirier et al. (2011), who matched their groups on a VIQ estimate that did not include digit span.

In some cases, difficulties in remembering the context may have also led to difficulties remembering the items. Only six studies have directly compared item and relational memory within the same task in ASD previously. Five of these studies found similar difficulties in ASD on item and relational tests, when participants were asked to remember line-drawings and their colours (Massand, 2011, Exp. 5), locations for dots in a grid and the temporal order of their presentation (Bowler et al., 2016), pictures of daily objects (Cooper et al., 2015; Semino et al., in preparation) or words (Bowler et al., 2004) and their screen locations. By contrast, Bowler et al. (2014) found intact item memory for pictures, colours, and locations, but difficulties remembering the combinations, i.e., items in colours or items in locations. In this study images were presented in a grid, which may have served as support for ASD participants' memory. In addition, one could argue that scenes, like the ones used in Cooper et al. (2015), were much more complex than single items in a grid and, therefore, inconsistencies in the findings may have been related to varying degrees of task complexity. This idea was supported by Bowler et al. (2016), who found that when presenting participants with dots in their locations in a grid, difficulties remembering the temporal order of their presentation at study disappeared, showing the support the grid provided for retrieval of order memory in ASD.

In conclusion, relating items to one another seems to be somewhat easier for ASD individuals than relating items to their context. Relating items can be difficult for persons with ASD when more taxing tasks are used, or difficulties become apparent when larger samples are tested. Difficulties in context memory in ASD generalise across various types of

context, and item memory can be difficult as well, when tested with tasks of similar complexity as relational tasks.

After having established the specific memory profile of ASD individuals in the reduced use of organisational strategies and material-inherent relatedness, the benefit from task support as well as specific difficulties in remembering subjective as well as objective context information for items, the thesis will now present theories that have been developed in an attempt to explain the memory profile in ASD.

1.4.2 Memory theories in ASD

1.4.2.1 Amnesia parallel, hippocampal patients and the relational binding account

Boucher and Warrington (1976) established the *amnesia parallel* of autism. Amnesia, resulting from damage to the temporal lobe, is characterised by a selective memory impairment affecting the creation of new long-term memories and/or the retrieval of older memories. Similarly to ASD individuals, amnesics were found impaired in free recall (Warrington & Weiskrantz, 1970, 1974), ABM (Dall'Ora, Sala & Spinnler, 1989) and EFT (Cole, Morrison, Barak, Pauly-Takacs & Conway, 2015). In contrast to ASD, amnesics have also shown general impairments in paired associate learning (Baddeley & Warrington, 1970), recollection and familiarity (Berry, Kessels, Wester & Shanks, 2014; Lombardi et al., 2016), as well as difficulties with priming (Berry et al., 2014; Ostergaard, 1999). These findings indicate that memory impairments in amnesia are much more pronounced than those found in ASD. A reason might be that brain damage in amnesia extends beyond the hippocampus. Structural abnormalities of the hippocampus, but not the whole temporal lobe region of the

brain, have been reported repeatedly[7] in ASD (e.g., Aylward et al., 1999; Bauman & Kemper, 2005; Nicolson et al., 2006; Maier et al., 2015; Schumann et al., 2004), and DeLong (1992) has hypothesised about the role of the hippocampus in the more general difficulties seen in ASD, such as rigid and repetitive behaviours (American Psychiatric Association, 2013), difficulties in the development (Loucas et al., 2008; Tager-Flusberg & Joseph, 2003) and use of language (e.g., Eales, 1993; Norbury & Bishop, 2002; Rapin & Dunn, 2003), and a lack of creativity (e.g., Boucher, 2007; Constable, Ring, Gaigg & Bowler, under revised review; Craig & Baron-Cohen, 1999). In addition, ASD is characterised by difficulties in social interactions, which are not central in amnesia. Most importantly, ASD is present from birth onwards, whereas amnesia is most often acquired later in life after the development of the brain is complete. Therefore, a better condition for comparison would be developmental amnesia, where brain lesions to the temporal lobe, frequently limited to the hippocampus, occur within the first few years of life (Vargha-Khadem et al., 2003). Because of the rarity of the condition, most studies are case reports. These indicated some similarities to ASD in the form of impaired EM but intact SM in developmental amnesia (Rosenbaum et al., 2011). However, studies also showed differences from ASD in developmental amnesia in terms of intact EFT (D'Angelo, Kacollja, Rabin, Rosenbaum & Ryan, 2015), intact relational memory (Hurley, Maguire & Vargha-Khadem, 2011), and transfer effects when taught (D'Angelo et al., 2015), indicating that some functions normally controlled by the hippocampus may be taken over by other brain regions in the course of development. It remains, however, unclear, if intact performance of individuals with developmental amnesia on these tasks occurs because of a restriction of the damage to the hippocampus (Adlam, Malloy, Mishkin & Vargha-Khadem, 2009), or because an early brain damage might have been compensated by

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[7] Studies are inconsistent as to whether the hippocampus is enlarged (Schumann et al., 2004) or smaller (Aylward et al., 1999) relative to TD individuals. Some studies found no between-group differences (Piven, Bailey, Ranson & Arndt, 1998).

continuing brain development. The second possibility raises the question why similar coping

mechanisms do not seem to happen in ASD or if they do why they are not as efficient.

Another account that sees the hippocampus as the base of difficulties in memory in

ASD is the *relational binding account* (Bowler et al., 2011), which proposes that individuals

with ASD show intact item memory, i.e., memory for single words or pictures, but they show

difficulties with relational binding, i.e., difficulties establishing a link between different items

or among items and their context, such as place, time, or colour. The capacity of relational

binding enables flexible retrieval of the event as well as its parts, and it is dependent on the

hippocampus (Opitz, 2010). Following the account, item memory in ASD should be intact

because it depends on brain regions outside the hippocampus, such as the perirhinal or

entorhinal cortex, which are not suspected to work differently in ASD (Bowler et al., 2011).

A question that still needs to be resolved is whether ASD individuals show an impairment in

relational processing (B. J. Smith et al., 2007), or whether they just present a preference for

item-specific processing and are, in principle, able to use relational processing but do not do

so spontaneously (Gaigg et al., 2008).

To explain why some tasks involving relational processing may be more difficult for

ASD individuals than others, Bowler et al. (2011) refered to Halford's (1992) *taxonomy of

cognitive development* (see Section 1.4.1.4). Halford (1992) described cognitive development

in stages of increasing complexity - *unary relations* describe the processing of individual

items, followed by *binary relations*, the processing of pairs of items, followed by higher

order relations such as *ternary relations*, the processing of relations among triplets of items.

Bowler et al. (2011) argued that the concept of ternary relations may also be able to explain

difficulties in other cognitive processes, outside the domain of memory, such as why

individuals with ASD show difficulties with joint attention, which requires them to see the

relations among themselves, another person, and an object. Even lower performance on tasks

of ToM such as the Sally-Anne task, described epreviously, can be explained as a difficulty in the processing of ternary relations (Bowler et al., 2005; Section 1.2.1).

Some inconsistencies in the findings as well as a lack of an overlap between findings in ASD and developmental amnesia, only involving the hippocampus as a responsible brain region, however, leave room for speculation about additional brain regions involved in ASD, which will be discussed in the next sections.

1.4.2.2   Complexity account and findings from frontal lobe patients

Another way to look at findings on memory in ASD is that of the *Complexity Account*, which was first described by Minshew et al. (1994), identifying ASD as a disorder of complex information processing, and which is described in detail previously (Section 1.2.3). The danger of post-hoc defining a task as complex because ASD individuals perform badly on it, led Bowler et al. (2011) suggest to use Halford's (1992) taxonomy of the complexity of relational processing as a way of operationalising complexity in a task (see Section 1.4.1.4). The complexity account draws on a parallel to patients with frontal lobe pathology, who, similarly to ASD individuals (see Section 1.2.2; Hill, 2004a & b), have been found to show difficulties in EFs (e.g., Alvarez & Emory, 2006). The frontal lobes are thought to be involved in complex information processing, because of their role in integrating information from all primary sensory cortices to strategically guide goal-directed actions (Koechlin & Summerfield, 2007). Anatomically, larger frontal cortices (Carper & Courchesne, 2005) as well as poor connections between distal brain regions (Courchesne & Pierce, 2005) have been reported for ASD individuals, supporting the idea that the frontal lobes may play a role in the differences observed in ASD.

In terms of memory, parallels in the reduced use of meaning and organisational strategies to support recall in ASD (Minshew & Goldstein, 2001) and in patients with frontal lobe lesions (Gershberg & Shimamura, 1995; Mangels, 1997; Stuss & Alexander, 2005) have

been reported. Further similarities were found in difficulties with EFT (Berryhill, Picasso, Arnold, Drowos & Olson, 2010), intact item memory and simultaneously difficulties associating information about time and place to items (Janowsky, Shimamura & Squire, 1989), difficulties remembering the temporal order of events (Shimamura, Janowsky & Squire, 1990), and more difficulties with unsupported compared to supported tests (Baldo & Shimamura, 2002) in patients with frontal lobe lesions. ABM problems in frontal lobe patients have been reported as a less prominent feature (Berryhill et al., 2010), in that they were only found in individuals that had additional difficulties in EFs (Sala, Laiacona, Spinnler & Trivelli, 1993). This finding parallels a recent study in ASD, where only the individuals with difficulties in EFs showed particularly reduced ABM (Maister et al., 2013). Another parallel to ASD was found in difficulties in more complex paired associative learning tasks testing flexibility in re-combining previously studied items in frontal lobe patients (Shimamura, Jurica, Mangels, Gershberg & Knight, 1995; see Gaigg et al., 2012 for results in ASD). In contrast to ASD participants, next to difficulties in unsupported free recall tests, patients with frontal lobe pathology also showed reduced cued recall and recognition memory (Wheeler, Stuss & Tulving, 1995). In addition, patients with frontal lesions have been shown to benefit from semantic relatedness of study materials (Kopelman & Stanhope, 1998), which is unlike ASD individuals (see Section 1.4.1.3). Finally, a direct test of the influence of frontal lobe functions on memory in ASD, utilising a test that had previously been successful in demonstrating EM impairments in frontal lobe patients, showed only few similarities (Bowler et al., 2010). In this task, participants were asked to study two lists of words from the same categories until they reached a criterion. There was either no support at study and/or at test, or support was provided in form of category labels at encoding and/or retrieval. The only similarity with Gershberg and Shimamura's (1995) frontal lobe patients was found in reduced clustering in the output of the ASD participants (Bowler et al., 2010).

The reported similarities and differences in memory in ASD and frontal lobe patients suggest that the frontal lobes are part of the story but that other brain regions should be considered in addition.

1.4.2.3 Ageing analogy - a combination of the frontal lobes and the hippocampus

A combination of both previously presented accounts is the *ageing analogy*, first proposed by Bowler (2007), noting that memory in ASD is similar to that of TD OA. TD OA first experience a decrement in the PFC, leading to a decrease in EFs, which is later on followed by volume changes in the hippocampus leading to problems with memory (Hedden & Gabrieli, 2004). This and the finding of an activation of the MTL and the frontal lobe during memory encoding (Buckner, Kelley & Petersen, 1999) and retrieval (Simons & Spiers, 2003), pointed to the role of both brain regions and their alternated connectivity (Hedden & Gabrieli, 2004) in memory in TD OA.

Behaviourally similar to ASD, TD OA have shown decreased performance on unsupported free recall compared to supported recognition test procedures (Craik & Anderson, 1999). Similar to the relational binding account in ASD (Bowler et al., 2011), an associative deficit hypothesis for TD OA suggests that older age is associated with particular difficulties in forming associations between units of experience in memory (Naveh-Benjamin, 2000), such as remembering locations of items (Chalfonte & Johnson, 1996; Kessels, te Boekhorst & Postma, 2005b), their colours (Chalfonte & Johnson, 1996), or the temporal order of their presentation (Rotblatt et al., 2015), leaving memory for single items relatively intact (Dumas & Hartman, 2003). Also similar to ASD, TD OA have shown reduced ABM (Levine, Svoboda, Hay, Winocur & Moscovitch, 2002), EFT (Cole, Morrison & Conway, 2013), as well as difficulties in memory monitoring (McDonough & Gallo, 2013), leaving implicit memory intact (J. H. Howard, Dennis, Howard, Yankovich & Vaidya,

2004). Finally, lower clustering in TD OA compared to younger adults on a free recall test of words may have been related to reduced age-related cognitive flexibility (Taconnat et al., 2009), whereby EFs would have been a mediator of the effects of older age on EM (Troyer, Graves & Cullum, 1994). In this context, Troyer et al. (1994) found that age did not predict recall performance anymore when the influence of EFs was partialled out. Put in other words this means that TD OA with good EFs would not differ from younger adults in their recall. As mentioned above, similar findings have been reported for ASD (Maister et al., 2013). These results suggested the importance of EFs for retrieving the relevant information out of a disorganised memory trace. In ASD individuals with executive dysfunction, poor EFs would not make up for a relational binding deficit in memory and, therefore, these individuals would show memory impairments. Further support for the notion that the hippocampus and the PFC are working together differently in memory in ASD in some way comes from a recent study showing activation in both brain regions following successful encoding in memory (Gaigg et al., 2015).

1.4.2.4 The parietal lobes or a combination of the frontal lobes, the hippocampus and the parietal lobes

Boucher and Mayes (2012) recently offered a possible alternative of a neural substrate of memory impairments in ASD – the parietal lobes. This view makes sense when considering parietal lobe abnormalities reported in ASD (Courchesne, Press & Yeung-Courchesne, 1993), and the importance of the parietal lobes for EM (Ally, Simons, McKeever, Peers & Budson, 2008; Cabeza, Ciaramelli, Olson & Moscovitch, 2008; Simons et al., 2008; Simons, Peers, Mazuz, Berryhill & Olson, 2010). Behaviourally, findings of intact memory for pairs of items (Berryhill, Drowos & Olson, 2009) were recently challenged by reports of impairments for more complex forms of associative learning in parietal patients (Ben-Zvi, Soroker & Levy, 2015), which parallel recent demonstrations in ASD (Gaigg et al., 2012). Similarly, memory

difficulties have been found to decrease with increasing task support in parietal patients (Adlam et al., 2009), and the parietal lobes have been shown to be involved in R judgements in R/K tasks (Wagner, Shannon, Kahn & Buckner, 2005), which have been reported to be reduced in both ASD (see Section 1.4.1.2) and parietal patients (Drowos, Berryhill, André & Olson, 2010). ABM and EFT were also found affected in parietal patients (Berryhill et al., 2010). Further, the parietal lobes, next to the PFC and the hippocampus, form part of a default network for ABM, EFT, and perspective taking (Buckner, Andrews-Hanna & Schacter, 2008), and they were found responsible for other functions that have been found to be impaired in ASD, such as motor planning (Fogassi & Luppino, 2005; Gowen & Hamilton, 2013), and imitation (Iacoboni et al., 1999; J. H. G. Williams, Whiten & Singh, 2004). Maister et al. (2013) recently hypothesised about an involvement of frontal, hippocampal, and parietal regions as the neural underpinnings of memory impairments in ASD. This idea was supported by findings of the involvement of all three brain regions in EM (Shimamura, 2014). As presented in Section 1.2.7, the parietal lobes were also found to play an important role in attention, with some attentional functions working differently in ASD (Section 1.2.7). How attention may be related to EM will be presented in Section 1.4.2.5.2.

Two final possibilities that would be supported by the great variation between individuals with ASD are that different neural substrates may be involved in different individuals with ASD (Boucher & Mayes, 2012), or that different brain regions are implicated to different extents across individuals.

1.4.2.5 Relation between memory findings and general cognitive theories in ASD

1.4.2.5.1 ToM deficit account

Perner, Kloo and Gornik (2007) argued that ToM ability (see Section 1.2.1 for ToM in ASD) is necessary for EM, i.e., to re-experience a past event. The authors referred to Tulving's (1985) definition of EM as remembering the past in the sense of reliving it, including mental time travel. This form of reliving the past is distinguished from knowledge about past events that has been acquired without directly having experienced the event, for example, because somebody else talked about the event. Experimentally, this distinction between Remembering and Knowing is measured using the R/K recognition memory paradigm (as discussed previously in Sections 1.3.2, 1.4.1.2). Perner et al. (2007) argued that in order to recognise an event as old, one needs to understand that one has a memory of the event because one experienced it previously. The memory is the representation of a previous experience and one understands the source for this memory. To do this, ToM is needed as a way of introspection. In relation to source monitoring this means, the more vivid details a representation of an event includes, the more likely it is judged as previously experienced rather than if one just knows the facts about the event. This is especially relevant for free recall tests, which provide no clues to the experience. Perner et al. (2007) emphasised, however, that ToM and EM develop in parallel and influence each other. Individuals with impairments in ToM would be expected to show difficulties in recollection and source monitoring because they would not be able to distinguish between events that they themselves have experienced, or that they were told about.

1.4.2.5.2   Atypical Attention account

Cabeza et al. (2008) presented an *Attention to Memory model* (AtoM) postulating two ways in which attention (see Section 1.2.7 for attention in ASD) plays a role in EM. In this model, the authors distinguished between *direct* and *indirect retrieval*, similarly to Moscovitch's (1992) distinction between *associative/automatic* and *strategic retrieval*. Cabeza et al. (2008) hypothesised that direct retrieval is controlled by the ventral parietal cortex and mediated by the MTL. This process needs little attention and works rather automatically in that attention is directly captured by information (bottom-up processing). Indirect retrieval, in contrast, is controlled by the dorsal parietal cortex, and it is mediated by the PFC. It is a strategic and effortful process that demands attention, and it is driven by the goal of the person trying to remember (top-down processing). Attention is not essential but it enhances memory efficiency. Individuals with a lesion in the ventral parietal cortex would be expected to show subtle difficulties in EM in free recall, but not when cues are provided at test, in recollection, but not when context is assessed by questions, and possibly in the simultaneous retrieval of several details.

The next accounts and their predictions concern less the system itself but rather the way information enters the system.

1.4.2.5.3 Weak Central Coherence and Atypical Perceptual Processing accounts

EPF (see Section 1.2.6) leads to a bias for processing low-level perceptual features with less processing of high-level features (Mottron & Burack, 2001). One example is a bias in favour of processing item information that leads to less processing of global information, i.e., the context (local versus global information according to the WCC – see Section 1.2.4). Difficulties with remembering context information and intact item memory are features that are also predicted by the relational binding account. Thereby, the question remains whether

enhanced item processing is a bias and ASD individuals are able to use relational processing if they choose to or are instructed to do so (which is what the EPF account - Mottron & Burack, 2001 and the later version of the WCC account - Happé, 1999 argue), or whether relational processing is defect in ASD and enhanced item processing is rather a compensatory mechanism (which is what the earlier version of the WCC account argues - Frith & Happé, 1994). In relation to that, Maister et al. (2013) argued that the PFC may be needed as a compensatory mechanism to inhibit or supress item processing so that relational processing can happen in ASD.

1.4.2.5.4 Increased Perceptual Discrimination account

Similarly to the WCC account, the Increased Perceptual Discrimination account (see Section 1.2.5) predicts better processing of individual features (e.g., Plaisted et al., 1998a), for example items. Maister et al. (2013) suggested that the PFC may be needed as a compensatory mechanism to specify additional retrieval cues or to engage in strategic search for the relevant information.

1.5 Aims of the thesis

After having established that persons with ASD show particular behavioural features in terms of difficulties in social interactions and routine-like behaviours, the literature review also showed that there are a number of cognitive theories trying to explain ASD in terms of differences in cognitive functions such as ToM, EFs, perception, processing styles, attention, and memory that individuals with the disorder show. None of the cognitive accounts has been successful in explaining all the features of the disorder. However, it is now established that ASD individuals present a characteristic profile in memory. Specifically, from the literature review it becomes clear that they have particular difficulties with relational processing. Because of the relevance of memory for daily life and because of the potential power of the

relational binding account in explaining ASD, the aim of the thesis was to put this particular account to the test. Only few tasks have so far, specifically, tested relational memory in ASD. Therefore, tasks were used that, specifically, probe relational processing and systematically compare relational memory to item memory within the same task. Another aim of the thesis was to try to find measures that would, in principle, be suitable for a wider population of individuals on the autistic spectrum, including those with limited language and/or intellectual abilities, who often get left out in research. Another group of participants that is scarcely researched are older ASD participants. Because of the importance of the effects of age on cognitive functions for care provisions and support programmes, it was of interest to run preliminary analyses of the effects of age on memory across the mid-adulthood-lifespan in cross-sectional designs to investigate if ASD and TD groups would differ. To achieve these aims this thesis includes five studies each testing large groups of adults with ASD and TD with broad age-ranges in the adulthood lifespan and IQs in the average range.

Experiment 1 served as a connection and extension to previous literature on recognition memory in ASD. Following Tulving (2002), recognition memory judgements are based on contributions of autonoetic and noetic consciousness. These contributions have been measured empirically by employing the R/K recognition memory procedure. Studies using this paradigm in ASD have consistently found reduced R but intact K responses (see Section 1.4.1.2) indicating particular difficulties in EM but intact SM. Previous studies, however, have mainly used verbal materials and, as ASD is related to particular difficulties in acquiring and developing language (Howlin & Asgharian, 1999; Loucas et al., 2008; Tager-Flusberg & Joseph, 2003), results may not be generalisable across different materials such as pictorial materials or ones that are hard to verbalise/name. Therefore, Experiment 1 tested the generalisability of previous results on R/K recognition by using meaningful and meaningless verbal and visual materials in a standard R/K recognition procedure. This study also aimed to

determine why groups differ in their R judgements, and what criteria they base their recognition decisions on by calculating sensitivity and response bias measures and by asking participants to justify their R responses. Finally, the underlying neural processes were of interest. Pupillary responses are a summed index of brain activity during a certain task. TD participants characteristically show larger pupils in response to previously presented as opposed to new items (pupil Old/New effect; Goldinger & Papesh, 2012) indicating that recollection is more cognitively demanding for them. Experiment 1 aimed to test whether the pupil Old/New effect would also be found for ASD individuals. An atypical pupil Old/New effect would imply altered neural processing in this group.

Following Experiment 1, which showed similar difficulties in EM for different materials and indicated difficulties in establishing relations in terms of R responses and R justifications, Experiment 2 aimed to directly test relational memory in ASD. In contrast to Experiment 1, where participants could choose which context from the study phase they wanted to remember and report for a R justification (subjective context memory), in Experiment 2 participants were directly asked to remember locations for objects in rooms (objective context memory). Experiment 2 also aimed to unify the memory distinctions of item/relational and implicit/explicit memory (previously presented in Section 1.3.2) to establish whether the difficulty in ASD is one of explicit retrieval or general relational processing extending to implicit memory and, therefore, to memory encoding, which is an open question in the ASD literature (see Section 1.4.1.3). To do this, an Inclusion/Exclusion paradigm was used (Jacoby, 1991, 1998) and fixations to the objects' previously presented old and new locations were measured.

While Experiment 2 demonstrated particular difficulties in remembering object-locations, the aim of Experiment 3 was to compare memory using the same experimental paradigm for single images (items), memory for location, temporal order, and memory for

study set (relations among subsets of items). Two previous studies suggested similar difficulties in ASD for different types of relations (Bowler et al., 2004, 2014). Studies directly comparing item and relational memory in ASD are inconsistent. Therefore, a paradigm was used with similar relational processing requirements for all four tasks. In addition, because ASD individuals present difficulties in developing language (Howlin & Asgharian, 1999; Loucas et al., 2008; Tager-Flusberg & Joseph, 2003), abstract shape images were used to control for the influence of language as well as for differences in previous experiences with the test materials.

Having established that different types of relational memory as well as item memory are difficult for persons with ASD, another area that is known to be associated with relational memory and that is supported by hippocampal function - spatial navigation - was assessed in Experiment 4. Item memory and relational processing are important factors for successful spatial navigation (Bohbot, Iaria & Pertrides, 2004; Youngstrom & Strowbridge, 2012). Previous studies on the topic show inconsistent results (see Table 4.1 in Section 4.1.1). One possible reason for these earlier inconsistencies is that poor EFs or attention differences are involved in the relational processing difficulties in ASD. Therefore, these processes were examined by measuring cognitive flexibility and by tracking eye movements.

Following Experiment 4, which showed spatial navigation difficulties related to relational processing but also EF and attention differences, the aim of the final study of this thesis was to test the hypothesis of atypical hippocampal functioning as a potential cause of difficulties in relational processing in ASD. This study employed a structural learning task from the non-human animal learning literature (Aggleton, Poirier, Aggleton, Vann & Pearce, 2009; Aggleton, Sanderson & Pearce, 2007; Sanderson, Pearce, Kyd & Aggleton, 2006), which has been shown to be sensitive to hippocampal damage in animal lesion studies. This study was particularly important for the conclusion and discussion sections of this thesis.

2   Chapter 2: Recognition memory

2.1   Experiment 1: Remember/Know recognition memory

2.1.1 Introduction

2.1.1.1   Theoretical background

Recognition memory judgements are supported by EM as well as SM (Tulving, 2002). While EM is our memory for personally experienced events including information about time and place, SM is a memory for timeless facts (Tulving, 2002). To measure their contributions to recognition memory empirically, the R/K procedure has been developed (Tulving, 1985). While R (EM) describes the process of recollection of information together with contextual details such as when, where, and how it was learned, K (SM) by contrast, describes a feeling of familiarity - a participant knows that an item was previously encountered but cannot report any contextual details. Several studies in ASD have utilised this procedure to measure the extent to which EM and SM are intact in ASD, and if recognition memory judgements are based on similar criteria and affected by similar factors as is the case in TD individuals. As presented in Section 1.4.1.2 and Table 1.1 previously, ASD individuals characteristically present a reduction in R responses (nine out of 13 studies in Table 1.1) that sometimes gets compensated by higher K responses (three studies) or Guess rates (one study) in comparison to TD participants. In two studies lower R responses in ASD had a knock-on effect on overall corrected recognition rates and medium to large effect sizes for between-group differences in at least three other studies suggested that between-group differences may have remained undetected because of a lack of statistical power, highlighting the need for investigations with larger samples. The well-replicated overall reduction in R responses in ASD may be related to a difficulty to distinguish between previously studied and new materials, as higher FA

rates (e.g., Gardiner et al., 2003), lower memory strength/sensitivity, and more lenient response criteria in the ASD compared to the TD group (Bowler et al., 1998, 2000) show.

Qualitatively, R and K responses seem to be comparable between groups in that manipulations that differentially affect remembering and knowing do so to the same extent in TD and ASD participants (Bowler et al., 2007). Moreover, previous studies inspecting justifications for reporting R and K experiences found that they are similar for both groups. Specifically, Bowler et al. (2000a & b) presented examples of justifications for R and K responses, with the note that these did not differ between groups. Souchay et al. (2013) asked their participants to justify R responses with source information that had been provided at study, for example, the colour of a picture or the gender of the person who spoke a word at study, and coded R justifications accordingly. Finally, Tanweer et al. (2010) asked participants for event details to justify R responses and calculated proportions of R responses that were followed by a justification without necessarily inspecting their quality. It is clear from these findings that none of these previous studies has inspected the quality of R justifications that participants provide spontaneously.

It is important to note, that the majority of R/K studies in ASD has utilised verbal materials (12 out of 15 in Table 1.1), one has used pictures, one, ABMs, and one, non-meaningful kaleidoscope images. No systematic investigations comparing R and K responses have been carried out that compare across these types of materials directly in ASD. There are, however, a number of reasons to suggest that the use of visual materials would be advantageous for ASD individuals when testing recognition memory. It is likely, that language develops atypically in most individuals with ASD with a large proportion of individuals showing delays or severe difficulties in language development (Baird et al., 2006; Bennett et al., 2008; Boucher, 2012; Loucas et al., 2008; Tager-Flusberg & Joseph, 2003). In addition, research showed that inner speech use in ASD is particularly related to verbal

ability (Lindstone, Fernyhough, Meins & Whitehouse, 2009; D. M. Williams & Jarrold, 2010), and while intact inner speech use in ASD was found for visual short-term memory (D. M. Williams, Bowler & Jarrold, 2012; D. M. Williams, Happé & Jarrold, 2008), ASD participants did not use inner speech on planning tasks (Wallace, Silvers, Martin & Kenworthy, 2009; D. M. Williams et al., 2012). Further, when remembering the temporal order of presentation of visuo-spatial material, Bowler et al. (2016) found that VIQ was related only to the performance of the ASD group. Both studies again indicate differences in how memory strengths and weaknesses manifest for different materials in ASD. Language atypicalities together with superior perceptual skills may give ASD participants an advantage if pictures were used as materials (Mottron & Burack, 2001; Mottron et al., 2006). This suggestion is supported by the *picture superiority effect* (Shepard, 1967) found in typical individuals, describing better memory for pictures over words. Finally, expected differences between verbal and visual materials are also supported by ERP studies in ASD (Massand, 2011). While ASD adults showed diminished ERP Old/New effects for words, they showed an enhanced ERP Old/New effect for visual stimuli, suggesting better processing of visual materials and supporting the prediction that memory for picture stimuli may be less impaired in ASD (Massand, 2011).

Another important reoccurring factor in ASD research is a difficulty in using meaning inherent in the study materials in ASD (see Section 1.4.1.3). ASD individuals have been reported not to use information inherent in the study materials to support their recall through organisation (e.g., categorical, semantic, or syntactic information; Gaigg et al., 2008; Frith, 1970a & b; Fyffe & Prior, 1978; Minshew et al., 1992; Tager-Flusberg, 1991), or to cluster information semantically the way TD individuals do (Bowler et al., 2008a; Hermelin & O'Connor, 1967; Minshew & Goldstein, 1993). Following these studies, one would predict better performance for meaningful compared to meaningless materials for TD individuals, but

similar performance across materials for ASD participants. On the other hand, one study that directly investigated the influence of meaning on memory for visual material in ASD showed that the worst memory performance was for meaningless shapes (Ameli, Courchesne, Lincoln, Kaufman & Grillon, 1988), suggesting superior performance for meaningful compared to meaningless materials also in ASD. Together, these studies point to the need for more systematic investigations directly examining the role of meaning for verbal and visual memory.

In TD participants, differential effects of picture superiority (Dewhurst & Conway, 1994; Rajaram, 1996) and meaning (Rajaram, 1998) were found for R and K responses, where pictures as opposed to words and more meaningful compared to less meaningful materials led to an increase in R responses, leaving K responses unaffected. No such studies have been done in ASD previously, however, studies investigating the influence of the division of attention, perceptual instructions, mode of presentation, and number of presentations, suggest that ASD participants make qualitatively similar R/K judgements compared to TD individuals (Bowler et al, 2007). Also in TD individuals, the detrimental effects of age on R recognition have repeatedly been reported (e.g., Mäntylä, 1993; McCabe, Roediger, McDaniel & Balota, 2009). Age does, however, not affect K recognition in TD participants. No such studies exist in ASD so far.

The current study was also motivated by the lack of studies on recollection and familiarity in ASD individuals with minimal language and/or intellectual impairments. Regarding recollection, Bigham et al. (2010) reported lower memory for the temporal order of the presentation of 16 everyday items in 29 ASD adolescents with intellectual impairments (two boys, M_{age} = 14 years, M_{BPVS} = 76) compared to 23 younger TD children, matched on verbal and non-verbal intellectual ability (five boys, M_{age} = 8 years, M_{BPVS} = 80), and 24 ID adolescents, matched on age and verbal and non-verbal intellectual ability (seven boys, M_{age} =

14 years, M_{BPVS} = 77). While both comparison groups performed similarly, it was unclear whether weak familiarity may have contributed to the observed recollection difficulties in ASD as familiarity was not tested in this study. Ni Chuileann and Quigley (2013), similarly, found reduced temporal order judgements for the presentation of everyday objects in 30 minimally verbal ASD children (22 boys, M_{age} = 10 years, M_{BPVS} = 61) compared to 27 children with Developmental Delay (DD), matched on age, verbal, and non-verbal intellectual ability (16 boys, M_{age} = 10 years, M_{BPVS} = 64), and 33 younger TD children, matched on non-verbal intellectual ability (19 boys, M_{age} = 6 years, M_{BPVS} = 71). Half the ASD group were at chance on this task, and persons with ASD performed significantly lower than the two comparison groups overall. The ASD children also showed lower familiarity for abstract shape images in a four forced-choice test, while the TD children performed at ceiling, suggesting familiarity and recollection as areas of difficulty in ASD individuals with lower verbal and intellectual abilities. The focus on temporal order memory in the two studies just reviewed indicates the need for studies testing other memory types such as spatial memory. In addition, these studies are not necessarily comparable to the studies reviewed above using R/K paradigms, where participants choose the context information they want to remember. Both studies show the difficulties associated with carrying out research with minimally verbal ASD individuals with intellectual difficulties. These individuals are under-researched because it proves very difficult to find suitable well-controlled paradigms to test them. As participants they often fail to understand the complex and difficult task instructions that are used in most of the paradigms employed in research on adults with ASD, who have relatively typical language and intellectual skills, and as a consequence little is known about a population that is most in need of investigations that would help to develop suitable interventions and training programmes. Suitable paradigms would need to avoid ceiling and floor effects in the ASD as well as in the comparison groups. One way to do this would be to

use measures that do not require a verbal response, such as measurements of the pupil size (pupillometry).

Traditionally, pupil dilation is seen as an indicator of cognitive load, for example, in working memory (e.g., Piquado, Isaacowitz & Wingfield, 2010) or visual search tasks (G. Porter, Troscianko & Gilchrist, 2007), where greater pupil dilation indicates higher cognitive load and an overload is demonstrated by a decrease in pupil size, possibly resulting from task disengagement. Physiologically, when the pupil dilates, the parasympathic nervous system gets inhibited by norepinephrine, controlled by the locus coeruleus (Goldinger & Papesh, 2012). Memory encoding is influenced by the release of norepinephrine and the subsequent effects on memory can be measured through pupil dynamics (Hoffing & Seitz, 2015). Pupillometry is non-invasive and pupil responses are a reflex that exists from birth and that operates independently of conscious awareness (Gomes, Montaldi & Mayes, 2015; Heaver & Hutton, 2011; Laeng, Sirois & Gredebäck, 2012), making it a good measure of memory. Similarly to ERPs, pupil responses have a good temporal sensitivity (Hartmann & Fischer, 2014), but in contrast to ERPs, they are relatively easy and cheap to record (Laeng et al., 2012), which would be an advantage if they turn out to be a clinically useful measure. In addition, small correlations between pupil dilation and ERPs indicate that the two measures assess different underlying processes (Steinhauer & Hakerem, 1992). Because of these advantages, pupillometry seems a good measure to test a wide range of individuals including less verbal ones.

Previous research on pupil size in ASD is sparse. In ASD children, larger pupils were found at baseline (C. J. Anderson & Colombo, 2009; Blaser, Eglington, Carter & Kaldy, 2014; but see Nuske, Vivanti & Dissanayake, 2014a), indicating an increased activity of the autonomic nervous system. Two other studies found a reduced pupillary response to fearful unfamiliar faces in ASD compared to TD children (Nuske, Vivanti & Dissanayake, 2014b;

Nuske, Vivanti, Hudry & Dissanayake, 2014c). No pupil size studies in ASD adults and no studies investigating pupil size in relation to memory in ASD exist, although pupil size measurements have proven a useful indicator for memory processes in TD individuals. A well-established finding is the pupil Old/New effect, where the pupil dilates more for items previously studied compared to new items. This effect is typically measured using a paradigm similar to a behavioural Old/New paradigm. Participants are presented with material to study and at test they are presented with old and new material. Instead of, or in addition to, being asked directly to distinguish between old and new items, participants' phasic pupil response to each stimulus is measured (Goldinger & Papesh, 2012). A series of studies indicated the pupil Old/New effect to be influenced by memory strength (Otero, Weekes & Hutton, 2011; Papesh, Goldinger & Hout, 2012), emotion (Võ et al., 2008), and the degree to which encoding and retrieval conditions matched (Papesh et al., 2012). It was found to be universal across different materials (Otero et al., 2011), and pupil size at encoding and retrieval distinguished between later correctly and falsely remembered materials (Montefinese, Ambrosini, Fairfield & Mammarella, 2013; Otero et al., 2011; Papesh et al., 2012). Investigations in amnesia compared to control participants showed the opposite effect, i.e., larger pupils were found for new compared to previously studied items in amnesics, representing a novelty response (Laeng et al., 2007) and indicating the potential of pupil size measurements to reveal memory abnormalities.

Previous studies using physiological measures have significantly enhanced knowledge about memory in ASD by showing differential neurophysiological activation underlying EM and SM in ASD compared to TD (Gaigg et al., 2015; Massand & Bowler, 2015; Massand, Bowler, Mottron, Hosein & Jemel, 2013). Measuring ERP responses, TD individuals showed an early mid-frontal Old/New effect (300-500ms) representing SM, which was missing in ASD individuals. A more focussed parietal Old/New effect (400-800ms) together with a

diminished late-onset right-frontal Old/New effect in ASD seem to support findings of reduced EM and R in ASD (Massand et al., 2013). Massand and Bowler (2015) replicated the absence of an early Old/New effect in ASD relating to SM. In addition, they found nonspecific activation in ASD during several time windows for SM instead of the late-onset Old/New effect found in the TD group.

Based on the literature reviewed above, the aims of the current chapter were the following. First, it was of interest to systematically compare EM and SM in ASD and TD adults by using the R/K recognition paradigm. It was aimed to test if previous results of reduced R and intact K responses can be replicated in this study and whether they can be generalised across different verbal and visual and meaningful and meaningless materials. Second, it was of relevance to inspect on what criteria participants base their recognition judgements and whether they may differ between groups. Third, it was aimed to investigate the potential effects of age on R and K judgements in both groups. Finally, it was of interest to test the pupil Old/New effect to see if results can be replicated with a second less verbal measure that also tests the underlying physiology of memory.

Based on these aims, a classic R/K recognition memory procedure was used, asking participants to study sets of verbal and visual meaningful and meaningless items. Their memory was tested presenting them with previously studied and new items asking them to, first, make an Old/New and, then, a R/K decision for items indicated as old. Participants were asked to justify their R responses and pupil size was measured in response to old and new items.

First, corrected recognition rates (Hit rates minus FAs) were examined. If ASD participants have particular difficulties with EM but not SM, they will show reduced R but similar K responses across all materials compared to TD participants. If persons with ASD show a picture superiority effect similar to TD participants, both groups' corrected

recognition rates will be higher for visual compared to verbal materials. If ASD participants show particular difficulties to use meaning inherent in the materials, then their corrected recognition rates for meaningful materials will be particularly lower compared to TD individuals. To follow the second aim, FA rates, sensitivity, response bias, and verbal R justifications were examined. If persons with ASD have difficulties distinguishing between previously studied old and unfamiliar new materials, they will show higher FAs and lower sensitivity rates compared to TD individuals. In addition, they will show more lenient response criteria, i.e., a higher bias to say yes to all items as opposed to TD participants. In addition, if ASD individuals struggle to use relational memory, their R responses will be based on specific episodic experiences associated with the encoding episode, whereas TD participants' R justifications will also be related to other episodic experiences outside the immediate study context. Regarding the third aim, if ASD participants' memory is similarly affected by age as TD participants' memory, both groups will show a similar difference in R recognition related to age but no age-difference in K recognition. Regarding the pupil Old/New effect, if ASD participants show difficulties to distinguish old and new items, these difficulties will also be apparent in pupil size. Unlike TD participants showing the typical pupil Old/New effect with larger pupils for previously studied compared to new items, persons with ASD will not show this effect indicating a different physiology underlying recognition memory in ASD. Finally, if the pupil Old/New effect measures a real memory phenomenon, pupil size data will correlate with behavioural memory data.

2.1.1.2 Predictions

Based on the evidence presented above, it was expected that both groups would show the typical R/K effect with more R compared to K responses for all materials and ASD individuals giving fewer R responses compared to TD individuals. In addition, both groups were expected to show the picture superiority effect with higher accuracy for pictures

compared to words. Both groups were expected to perform better on meaningful compared to meaningless materials with the TD group outperforming the ASD group particularly on meaningful material. It was predicted, that picture superiority and meaning would primarily influence R judgements and that these interactions would be similar for both groups. Lower overall recognition rates were expected for ASD compared to TD participants, because the large sample tested provided sufficient statistical power. It was also predicted that ASD participants would show difficulties in distinguishing between old and new items apparent through more lenient response criteria in terms of higher FA rates, higher response bias, and lower sensitivity, and that they would justify their R responses primarily based on information from the immediate study episode.

Next to similar effects of age on memory as in TD OA (*parallel development* - Geurts & Vissers, 2012), stronger (*double jeopardy* - Geurts & Vissers, 2012) or weaker effects of age on cognitive functions in older ASD individuals (*safeguard hypothesis* - Geurts & Vissers, 2012; Lever & Geurts, 2016) were possible, all with significant implications for care provisions. In addition, the ageing analogy (Bowler, 2007) would predict similar performance of younger ASD individuals compared to TD OA.

Regarding pupillometry, it was expected that TD participants would show the typical pupil Old/New effect with larger pupils for studied compared to new items for all materials, replicating previous literature. Based on the literature, a typical pupil Old/New effect in ASD would implicate similar and intact underlying mechanisms for recognition memory judgements as in TD individuals, whereas a reduction of this effect in ASD would indicate abnormalities in the mechanisms underlying memory difficulties observed in ASD. Based on ERP Old/New studies in ASD, it was expected that the pupil Old/New effect would either be diminished or enhanced in ASD as compared to TD individuals.

2.1.2 Methods

2.1.2.1 Participants

This section concerns some general comments about participant matching, recruitment, participant characteristics, and comorbid disorders in ASD participants that apply to all experiments presented in this thesis.

The comparison between ASD and typical development was of interest in this thesis in order to inform about the ways in which the two groups differ. To do this effectively, the two groups needed to be matched. As there is no perfect matching strategy, the best choice of a matching criterion or variable depends on the questions that need to be answered (Burack, Iarocci, Flanagan & Bowler, 2004). The dilemma in matching on intellectual ability or, in more general, any ability in ASD is that ASD individuals show profiles of particular strengths and difficulties in various areas. Matching on strengths would overestimate their performance in another area. Similarly, matching on a weakness would underestimate performance in other areas (Burack et al., 2004). A compromise is, therefore, to match on a combined score that includes areas, where individuals perform well, and those, where they do not perform so well. Since the area of interest in this thesis was memory, and since it was found that memory is significantly related to intellectual ability (Alexander & Smales, 1997), a combined score of strengths and weaknesses in intellectual ability would be Full-scale IQ (FIQ; Burack et al., 2004). However, two individuals with the same or similar FIQs do not necessarily show the same profile in terms of VIQ and Performance IQ (PIQ). Non-verbal/performance skills have often been found to be superior compared to verbal ability in ASD (e.g., Happé, 1994; Joseph, Tager-Flusberg, & Lord 2002; but see Siegel, Minshew & Goldstein, 1996). Therefore, for the studies presented in this thesis, FIQ as well as VIQ and PIQ were chosen as matching variables, and TD and ASD participants were individually matched with a

difference of less than 10 IQ points in each variable. IQ was measured using the third or fourth edition of the Wechsler Adult Intelligence Scale (WAIS-III[UK] or WAIS-IV[UK]; The Psychological Corporation, 2000; 2008). Like the WAIS-III[UK], the WAIS-IV[UK] determines an FIQ value. The equivalents of VIQ and PIQ in WAIS-III[UK] are called Verbal Comprehension (VCI) and Perceptual Reasoning Index (PRI) in WAIS-IV[UK]. Matching on either WAIS-III[UK] or WAIS-IV[UK] scores seemed unproblematic, since FIQs, VIQ and VCI, and PIQ and PRI of the two test versions were found to be highly correlated ($r = 0.94$, $r = 0.91$, $r = 0.84$; Wechsler, 2008). In general, the WAIS is a widely-used, valid and reliable standardised measure (K. C. H. Parker, Hanson & Hunsley, 1988), even for clinical samples (Zhu, Tulsky, Price & Chen, 2001), and presents stable measurements across a wide age-range (Bowden, Weiss, Holdnack & Lloyd, 2006). Another important variable to consider when matching participants is age. As we age, our brain changes and these changes affect cognitive processes (Johnson & Munakata, 2005; Luna, Garver, Urban, Lazar & Sweeney, 2004), such as memory (Park et al., 1996). Therefore, in this thesis groups were matched on chronological age (CA) with a difference of at maximum +/- 2 years of age. In addition, gender differences have been reported for cognitive functions in general (Weiss, Kemmler, Deisenhammer, Fleischhacker & Delazer, 2003), and for memory, in particular, with an advantage in verbal tasks for women and in spatial tasks for men (Andreano & Cahill, 2009). Further, ASD is 4 times more common in men than in women (Rivet & Matson, 2011). Therefore, the numbers of men and women in the ASD and TD samples of this thesis were equated, with the majority of participants being male.

Samples sizes were selected based on previous research and power calculations using G*Power (Faul, Erdfelder, Lang & Buchner, 2007). Participants were mainly recruited through a database of individuals with whom the Autism Research Group at City, University of London is in regular contact. In addition, participants got in contact through word of

mouth or flyers. ASD individuals were also recruited through support groups and advertisements with the National Autistic Society. TD individuals were also recruited through advertisements in newspapers. All participants were native English speakers. TD individuals were only included if they did not report taking psychotropic medication or having a personal or family history of a psychological or neurodevelopmental disorder. Participants were chosen to be adults of intelligence within the average range (100 +/- 2 Standard Deviations - SD). In addition, groups spanned a large age-range across the mid-adult lifespan (20-65 years of age) to aim for a wide generalisability of the findings and to run preliminary analyses of the effects of age on memory in cross-sectional designs. All participants were reimbursed for their time according to standard university fees and their travel expenses were paid. All studies were approved by the ethics committee of the Psychology Department of City, University of London and the procedures used in the studies adhere to the guidelines set out by the British Psychological Society.

All ASD individuals included in the studies had received a clinical diagnosis according to DSM-IV-TR criteria (American Psychiatric Association, 2000), which was confirmed by a review of their diagnostic documents. As a means of sample description, all participants filled in the Autism-Spectrum Quotient (AQ; Baron-Cohen, Wheelwright, Skinner, Martin, & Clubley, 2001)[8] - a self-report instrument that measures the degree of autistic traits within an individual. The authors of the instrument proposed a continuum that ranges from ASD to "normal" and the questionnaire identifies where on the continuum an individual is located. Within this thesis, the AQ was used to characterise the ASD samples in terms of autistic traits to enable a comparison with ASD populations used in other studies, and to define an exclusion criterion for TD individuals, who were only included if their AQ total score was below the suggested cut-off of 26 (Woodbury-Smith, Robinson, Wheelwright

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[8] This was the case for all participants in all experiments except for one ASD individual in Experiment 2 and one ASD individual in Experiment 5, who did not have time to fill in this measure.

& Baron-Cohen, 2005). Although the AQ has been found to be reasonably reliable in its measurement (Stewart & Austin, 2009), factor structures were not replicated (e.g., Kloosterman, Keefer, Kelley, Summerfeldt & Parker, 2011). In addition, the AQ did not distinguish well between (milder forms of) ASD and other mental health conditions (Ketelaars et al., 2008), and ASD individuals may underestimate the level or number of their autistic traits (Johnson, Filliter & Murphy, 2009). Although the AQ has been validated in its use for the measurement of autism-like traits through studies showing behavioural overlap in the performance of ASD participants and individuals with high scores on the AQ (e.g., Grinter et al., 2009; Von dem Hagen et al., 2011; Wyer, Martin, Pickup & Macrae, 2012), Gregory and Plaisted-Grant (2016) cautioned against the use of the AQ as a proxy for ASD because even if the AQ measures autism-like traits, this does not mean that it necessarily measures autism and, therefore, similar results, for example, in visual search tasks in ASD and high-AQ populations may have different reasons. Despite its short-comings the AQ seems to be a useful tool for the screening of a TD population and to enable a comparison between different ASD samples. Also for the purpose of ASD sample description in terms of clinical features and their severity, where time permitted, ASD participants were asked to complete the ADOS (Lord et al., 1989) - a semi-structured behavioural observation instrument. It was administered by researchers (including the author of this thesis) trained to research reliability standards on this instrument. ASD participants with scores just below the total cut-off of seven on the ADOS were, nevertheless, included in the sample since all individuals had received a clinical diagnosis of an ASD previously.

Comorbid medical as well as mental health conditions are 3 - 4 times more common in ASD compared to TD individuals. In a recent study, ASD adults were most commonly affected by anxiety, depression, OCD, and schizophrenia (Croen et al., 2015). They also reported more often seizures, epilepsy and sleep problems (Levy et al., 2009; Tuchman &

Rapin, 2002). In addition, medication use is very common in ASD, as recent reports show. In a longitudinal study, 60 % of ASD adults over 20 years of age were taking psychotropic and 50 % non-psychotropic medication. Over a 4-year period, however, these numbers increased to 70 % psychotropic and 60 % non-psychotropic medication, with antidepressants and antipsychotics being the most common medication (Esbensen, Greenberg, Seltzer & Aman, 2009). Inclusion of ASD individuals with comorbidities and medication use in research samples are likely to increase the heterogeneity of the samples and, therefore, the variation in the results. However, not including them would lead to a smaller and less representative sample, and the results would be less generalisable to the rest of the ASD population. Therefore, ASD individuals with comorbid disorders and medication were included in the samples of this thesis and a record of their disorders and medication was taken.

2.1.2.1.1   Behavioural data

Power calculation using G*Power (Faul et al., 2007) to determine the sample size needed to detect the predicted between-group difference in R responses showed that 32 participants in each group were needed to detect an effect of the size of Cohen's $d = 0.75$[9] with a power of 0.90. Thirty-two ASD adults (27 men, $M_{age} = 43.50$ years, age range: 27-65 years) were individually matched on VIQ/VCI, PIQ/PRI, and FIQ, as measured by the WAIS-III[UK] or WAIS-IV[UK] (The Psychological Corporation, 2000; 2008) to 32 TD adults (25 men, $M_{age} = 43.80$ years, age range: 22-65 years). Groups were closely matched on gender, $X^2 = 0.41$, $p = .52$, and CA, and ASD participants scored significantly higher on the AQ (Baron-Cohen et al., 2001; see Table 2.1). Time permitted to assess 24 persons with ASD with the ADOS (Lord et al., 1989). Five of these scored just below the cut-off of seven for the total score on

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[9] The effect size was estimated by averaging the effect sizes reported in the R/K studies presented in Table 1.1, excluding the experiments in Bowler et al., 2007, as the purpose of these studies was to test the influence of manipulations on R and K responses in ASD and TD individuals rather than to detect a potential difference between groups in R responses.

this instrument, but they were retained in all analyses because they all had a confirmed clinical diagnosis established by suitably qualified clinicians.

Table 2.1

Descriptive statistics for ASD and TD individuals, who participated in Experiment 1.

Measure	ASD (27m, 5f)		TD (25m, 7f)			Cohen's		
	M	*SD*	*M*	*SD*	*t*(df)	*p*	*d*	CI
Age (years)	43.50	12.2	43.80	12.4	0.10 (62)	.92	0.03	-0.47, 0.51
VIQ/VCI[a]	111	15.7	112	14.3	0.37 (62)	.72	0.09	-0.40, 0.58
PIQ/PRI[b]	105	15.0	105	13.8	0.12 (62)	.90	0.03	-0.46, 0.52
FIQ[c]	110	14.7	109	13.6	0.12 (60)	.91	0.03	-0.47, 0.53
AQ[d]	35.63	6.47	15.09	6.50	12.66 (62)	.00	3.16	2.40, 3.86
ADOS-C[e]	2.79 (0-6)	1.5						
ADOS-RSI[f]	5.79 (1-13)	2.8						
ADOS-Total[g]	8.58 (5-17)	3.4						
ADOS-Im[h]	1.26 (0-2)	0.6						
ADOS-SB[i]	1.29 (0-5)	1.4						

Note. [a]VIQ - Verbal IQ (WAIS-III[UK]) or VCI - Verbal Comprehension Index (WAIS-IV[UK]). [b]PIQ - Performance IQ (WAIS-III[UK]) or PRI - Perceptual Reasoning Index (WAIS-IV[UK]). [c]Full-scale IQ (WAIS-III[UK] or WAIS-IV[UK]), available for 31 TD and 31 ASD individuals. [d]AQ - Autism-Spectrum Quotient. [e]ADOS - Communication subscale. [f]ADOS - Reciprocal Social Interaction subscale. [g]ADOS Total score - Communication + Reciprocal Social Interaction. [h]ADOS - Imagination/Creativity subscale. [i]ADOS - Stereotyped Behaviours and Restricted Interests subscale. ADOS scores are presented with range in brackets.

ASD participants with comorbidities and/or medication use were included in the sample to increase the generalisability of the findings, as ASD is characterised by high rates of comorbidities and medication use (Croen et al., 2015; Esbensen et al., 2009). In the current sample, 44 % of ASD participants reported comorbidities and/or psychotropic medication use. Depression (43 %), anxiety disorder (14 %), ADHD (14 %), and dyslexia (14 %) were most common. In addition, OCD (7 %) and schizophrenia (7 %) were reported, and 57 % of ASD participants took antidepressants, and 21 % reported taking antipsychotic medication. ASD individuals with and without comorbidities and medication use did not differ significantly in terms of gender, $X^2 = 0.03$, $p = .85$, CA, VIQ/VCI, PIQ/PRI, and FIQ, $t_{max} < 0.91$, $p_{min} > .36$, Cohen's $d_{max} < 0.33$, 95 % $CI_{max}(-0.39, 1.02)$. In addition, analysing the data without ASD individuals that reported comorbidities and/or medication use left the results reported below unaffected.

2.1.2.1.2 Pupillometry data

Of the 64 participants tested, pupillometry data were not available for five ASD (four men, $M_{age} = 49.91$ years, age range: 32-65, $M_{VIQ/VCI} = 113$, $M_{PIQ/PRI} = 101$, $M_{FIQ} = 108$) and two TD individuals (two men, $M_{age} = 41.10$ years, age range: 36-46, $M_{VIQ/VCI} = 96$, $M_{PIQ/PRI} = 94$, $M_{FIQ} = 95$), who did not differ significantly from the rest of the sample in terms of gender, $X^2_{max} = 0.60$, $p_{min} = .44$, CA, VIQ/VCI, PIQ/PRI, and FIQ, $t_{max} < 1.71$, $p_{min} > .09$, Cohen's $d_{max} < 1.25$, 95 % $CI_{max}(-0.25, 2.67)$. The final sample for the pupillometry analyses, therefore, consisted of 27 ASD (23 men, $M_{age} = 42.31$ years, age range: 27-64 years) and 30 TD adults (23 men, $M_{age} = 43.98$ years, age range: 22-65 years), matched on gender, $X^2 = 0.66$, $p = .42$, CA, VIQ/VCI, PIQ/PRI, and FIQ (see Table 2.2).

Table 2.2

Descriptive statistics for ASD and TD individuals in Experiment 1 for whom pupillometry data were available.

| Measure | ASD (23m, 4f) | | TD (23m, 7f) | | | | Cohen's | |
	M	*SD*	*M*	*SD*	*t*(df)	*p*	*d*	CI
Age (years)	42.31	11.5	43.98	12.7	0.52 (55)	.61	0.14	-0.38, 0.66
VIQ/VCI[a]	110	15.0	113	14.0	0.72 (55)	.47	0.19	-0.33, 0.71
PIQ/PRI[b]	106	15.3	106	13.8	0.12 (55)	.91	0.03	-0.49, 0.55
FIQ[c]	110	14.8	110	13.5	0.09 (53)	.93	0.02	-0.51, 0.55
AQ[d]	36.07	6.0	14.97	6.7	12.53 (55)	.00	3.32	2.48, 4.07
Baseline pupil	3.21	0.57	3.17	0.45	0.34 (55)	.74	0.09	-0.43, 0.61
ADOS-C[e]	2.52 (0-5)	1.4						
ADOS-RSI[f]	5.76 (1-13)	2.9						
ADOS-Total[g]	8.29 (5-17)	3.4						
ADOS-Im[h]	1.15 (0-2)	0.6						
ADOS-SB[i]	1.14 (0-5)	1.4						

Note. [a]VIQ - Verbal IQ (WAIS-III[UK]) or VCI - Verbal Comprehension Index (WAIS-IV[UK]). [b]PIQ - Performance IQ (WAIS-III[UK]) or PRI - Perceptual Reasoning Index (WAIS-IV[UK]). [c]Full-scale IQ (WAIS-III[UK] or WAIS-IV[UK]) was available for 26 ASD and 29 TD individuals. [d]AQ - Autism-Spectrum Quotient. [e]ADOS - Communication subscale. [f]ADOS - Reciprocal Social Interaction subscale. [g]ADOS Total score - Communication + Reciprocal Social Interaction. [h]ADOS - Imagination/Creativity subscale. [i]ADOS - Stereotyped Behaviours and Restricted Interests subscale. ADOS scores are presented with range in brackets.

Five ASD (four men, M_{age} = 45.73 years, age range: 33-59, $M_{VIQ/VCI}$ = 112, $M_{PIQ/PRI}$ = 102, M_{FIQ} = 108) and eight TD participants (seven men, M_{age} = 41.60 years, age range: 26-56, $M_{VIQ/VCI}$ = 116, $M_{PIQ/PRI}$ = 111, M_{FIQ} = 114), who did not differ significantly from the rest of the sample in terms of gender, X^2_{max} = 0.72, p_{min} = .40, CA, VIQ/VCI, PIQ/PRI, and FIQ, t_{max} < 1.22, p_{min} > .23, Cohen's d_{max} < 0.51, 95 % CI_{max}(-0.33, 1.31), did not make behavioural mistakes, therefore, excluding them from further pupil analyses dividing data according to behavioural accuracy. The remaining 22 ASD (19 men, M_{age} = 41.53 years, age range: 27-64 years) and 22 TD (16 men, M_{age} = 44.85 years, age range: 22-65 years) adults were still matched on gender, X^2 = 1.26, p = .26, CA, VIQ/VCI, PIQ/PRI, and FIQ, t_{max} < 0.88, p_{min} > .38, Cohen's d_{max} < 0.27, 95 % CI_{max}(-0.33, 0.85).

2.1.2.2 Materials

Table A1.1 in Appendix 1 gives an overview of all words, pictures, shapes, and non-words used in this study (see Figure 2.1 for examples). Four lists of 10 pictures and their verbal labels each were selected from Snodgrass and Vanderwart (1980), to allow for each item to be presented equally often as a word or a picture and as a to-be-remembered target or a lure item. Presentation order was counterbalanced across participants, and there were no significant differences between the four final lists in letter number, word frequency, name agreement, image agreement, familiarity ratings, and complexity ratings (see Table A1.2 in Appendix 1). To select *shape* stimuli, 120 images from Haenschel et al. (2007) were presented for 3 s each on a grey background in the centre of a laptop screen to 30 City, University of London undergraduate students (10 men, M_{age} = 34.47, SD_{age} = 12.04), with the request to indicate how difficult they found it to come up with a name for each shape on a 10-point scale (0 - very easy to 10 - very difficult). A second pilot study involving five ASD and 10 TD individuals indicated that the 20 shapes that had been rated as the most difficult to name ($M_{difficulty}$ range = 6.90-8.13) were too difficult to remember under the conditions of the

main experiment, whereas the shapes that had been rated as the easiest to name ($M_{difficulty}$ range = 3.23-5.33) yielded memory performance well above chance. To avoid floor effects, the 20 easiest to name shapes were selected for two lists of 10 items each for counterbalanced presentation across participants. The 20 two and three syllable *non-words* from Gathercole, Willis, Emslie and Baddeley (1991) formed two lists of 10 items for counterbalanced test presentation, with the exception that the words 'bannow' and 'glistering' were replaced by 'honder' and 'natem' because using google search the former turned out to be the name of a place in Ireland and a meaningful word.

To avoid pupil size estimation bias resulting from eye movements (Brisson et al., 2013), the above described materials and fixation crosses were presented in the centre of the screen and images were large enough to recognise but small enough to see them without the need for eye movements. Shape images measured 3 cm x 3 cm, pictures had the size of 5 cm x 4 cm, and words and non-words were about 6 cm long and 2 cm high. Avoiding systematic changes in pupil size because of the pupil light reflex all materials were presented on the same grey background and images were black and white to ensure similar luminance[10] within and across conditions. Old (studied) and new (unstudied) sets of materials were counterbalanced across participants to control for any systematic differences in luminance between sets. In addition, the items were presented in blocks of the same material type, i.e., shapes, pictures, words, and non-words were never intermixed within one block. Luminance measurements for shapes and pictures were taken across the whole image using a Konica Monolta LS-100 luminance meter. Although meaningful pictures (M = 159.28 cd/m^2, SD = 11.65) were significantly brighter, $t(43.10)$ = 22.16, $p < .0001$, Cohen's d = 4.30, 95 % CI(3.36, 5.24), than meaningless shapes (M = 117.36 cd/m^2, SD = 1.92), the different sets of

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[10] Pupil size is measured best when the eyes look straight on the screen. If the eyes move, the pupil appears distorted on the camera of the eye-tracker leading to an over- or underestimation of the real pupil size. Luminance needs to be kept constant because the pupil gets smaller when luminance is higher.

shapes, $t(18) = 0.15$, $p = .89$, Cohen`s $d = 0.06$, 95 % CI(-0.81, 0.94), and pictures, $F(3,36) =$
1.32, $p = .28$, $\eta^2 = .10$, were well matched in terms of luminance (see Table 2.3).

Table 2.3

Luminance in cd/m^2 for sets of meaningless shape images and meaningful pictures used in Experiment 1.

	Set A	Set B	Set C	Set D
	M (*SD*)	*M* (*SD*)	*M* (*SD*)	*M* (*SD*)
Shapes	117.29 (1.81)	117.42 (2.12)	-	-
Pictures	164.71 (11.87)	156.41 (8.27)	155.62 (8.54)	160.37 (15.74)

Skirt	**Toaster**	**Elephant**
Natem	**Skiticult**	**Frescovent**
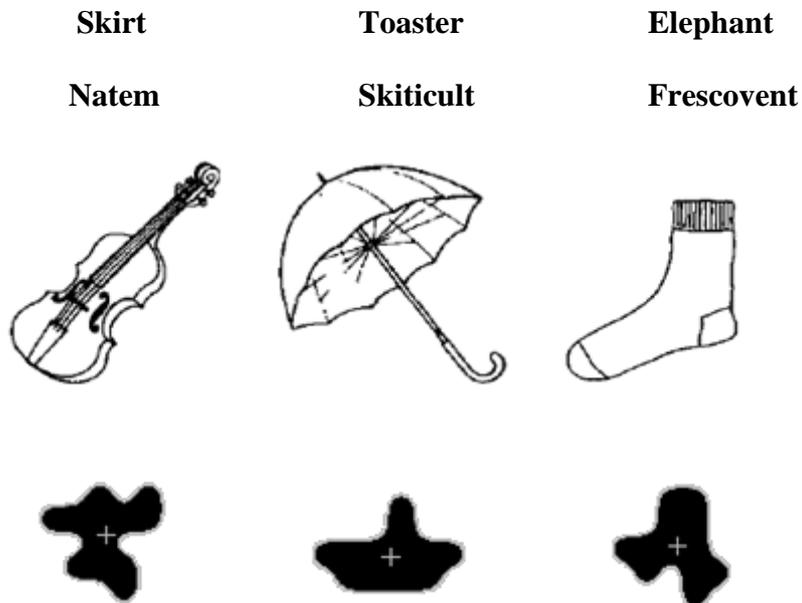
Figure 2.1. Examples of materials used in Experiment 1, from top to bottom - words, non-words, pictures, and shapes.

2.1.2.3　Procedure

Like in the other studies reported in this thesis, Experiment 1 used a recognition memory paradigm that offered task support in terms of providing some cue to the to-be-remembered information at test.

2.1.2.3.1　Remember/Know recognition test

Using the R/K procedure, a participant is asked to judge the kind of memory they have for items that they clearly identify as studied previously. For R responses, the participant needs to remember clearly the context or time of studying the item, i.e., any information about the actual study episode, in addition to the item. For K responses, a participant indicates that they simply know that the item was presented without remembering any additional contextual information - the item feels familiar to them. Special about this procedure is that it assumes recollection and familiarity as mutually exclusive processes, whereas all other models of recognition memory assume that they are independent. As opposed to other procedures, participants are asked for subjective reports to indicate a R or K response and, therefore, they are not restricted in the information that they remember (Yonelinas, 2002). Research investigating the influence of instructions and terminology on the R/K procedure found that using neutral terminology such as *Type A* and *Type B* memory instead of *Remember* and *Know* led to more accurate results, in that FA rates for R responses were reduced (McCabe & Geraci, 2009). In addition, using a R/K judgement after an Old/New judgement as a two-step procedure rather than combining both judgements in a R/K/New procedure as a single-step, also produced more accurate results (Eldridge, Sarfatti & Knowlton, 2002). In the R/K/New procedure participants did not reliably distinguish between old and new items, leading to increased FA rates for K responses (Eldridge et al., 2002). Therefore, a Guess category can be helpful to increase accuracy (Eldridge et al., 2002).

In the study phase of the current experiment, participants were asked to memorise four blocks of 10 words, pictures, shapes or non-words. Blocks were presented in counterbalanced order across participants using a Latin Square, with a matched pair of participants (one ASD and one TD individual with similar IQs) receiving identical presentation orders of the materials. Individual item presentation lasted 2 s and was followed by a 1 s blank, which was presented in the same grey as the background for the materials. Right after study, participants saw four blocks with 20 items each sorted by material type, half of which had been studied previously. The order of block presentation was the same as at study to ensure the same length of time between study and test for all materials. Following a fixation cross presentation for 0.25 s (baseline), each item was presented for 1.75 s at test, after which the R/K procedure followed. The procedure was presented in two steps. First, participants were asked to indicate which items they had seen previously by pressing the appropriate key on the keyboard (Old/New judgement). For items indicated as old, a R/K judgement followed, which was presented in the form of Type A versus Type B memory. Participants were asked to respond with *Type A* (R response), if they could remember clearly information about the actual study episode, for example, the context or the time of studying the item in addition to the item. A *Type B* memory (K response) was that they simply knew the item had been presented without remembering any additional contextual information (for the exact R/K instructions given to participants see Appendix 1 Section A1.3). Before the test, participants had been given examples of R and K responses, and at test they were asked to justify their responses verbally. Verbal responses were tape-recorded for further analyses. Figure 2.2 illustrates the procedure of the task.
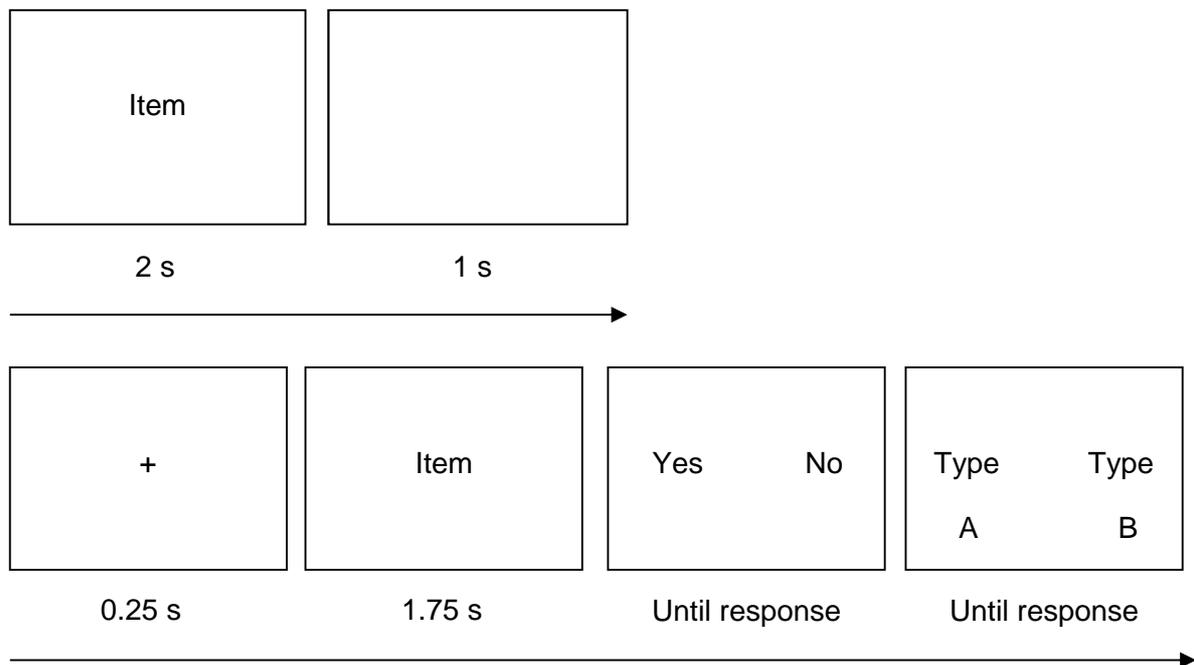
Figure 2.2. Procedures for study (top) and test phases (bottom) of Experiment 1.

2.1.2.3.2 Pupillometry

After a standard five-point calibration procedure, pupil diameter was recorded throughout the task with a Tobii TX300 eye-tracker with a sampling rate of 120 Hz. Customised Matlab routines were used to remove artefacts, linearly interpolate blinks, and to extract the data. For linear interpolation, the five samples before a blink and the five samples after a blink were averaged and linearly interpolated so that missing values were incremented ending up with a straight line connecting values before and after the blink. Applying a low-pass Butterworth filter with a cut-off frequency of 1 Hz, high-frequency noise in the data (e.g., caused by partial blinks) was removed. The data for each eye were interpolated and filtered before averaging them across the two eyes. A pupil size ratio was then calculated (Heaver & Hutton, 2011) to control for natural pupil size fluctuation and differences in pupil size between participants at baseline. For this, the maximum pupil size during item presentation (i.e., the task-evoked pupillary reflex) was divided by the maximum pupil size at baseline. Ignoring data for the first test trial to reduce noise in the data following the change from study to test,

the data were averaged across trials separately for each material type and separately for studied (old) and unstudied (new) items. To investigate potential pupil size differences for correctly and incorrectly remembered items, encoding and retrieval pupil size data were split up according to behavioural accuracy. To avoid a loss of data, correct and incorrect data were collapsed across the different materials, because not all participants made mistakes for all materials. To enable a detailed analysis of correct and incorrect responses to old and new items for retrieval, the pupil size data were sorted according to the four response types from signal detection theory, i.e., Hits, FAs, Misses, and Correct Rejections (CR).

2.1.3 Results

The behavioural raw data were scored in terms of Hits (percentage of yes responses to studied items), FAs (percentage of yes responses to lure items), and corrected recognition rates (Hits minus FAs). Results were analysed using Chi-Squared tests, bivariate correlation and linear regression analyses, independent samples t-tests, and repeated measures ANOVAs. Greenhouse Geisser correction (GGC) was applied, when the Sphericity assumption was violated, and Bonferroni corrected post hoc tests were used to further investigate significant differences between conditions. The level of significance was set to .05 and Cohen's *d* and partial Eta-Squared are reported as effect size measures.

2.1.3.1 Accuracy behavioural test

2.1.3.1.1 Corrected recognition

The data, presented in Table 2.4 and Figure 2.3, were analysed using a 2 (Group [ASD, TD]) x 2 (R/K [Remember, Know]) x 2 (Modality [verbal, visual]) x 2 (Meaning [meaningful, meaningless]) repeated measures ANOVA. This showed significant main effects of *Group*, $F(1,62) = 17.10$, $p < .0001$, Cohen's $d = 1.03$, 95 % CI(0.50, 1.54), with higher corrected

recognition rates for TD compared to ASD participants, *R/K*, $F(1,62) = 120.63$, $p < .0001$, Cohen's $d = 2.35$, 95 % CI(1.88, 2.78), with higher corrected recognition for R compared to K responses, *Modality*, $F(1,62) = 5.04$, $p < .05$, Cohen's $d = 0.35$, 95 % CI(0.00, 0.70), with higher corrected recognition for visual compared to verbal materials, and *Meaning*, $F(1,62) = 20.06$, $p < .0001$, Cohen's $d = 0.61$, 95 % CI(0.26, 0.96), with higher corrected recognition for meaningful compared to meaningless materials. A two-way *Group x R/K* interaction (see Figure 2.3 left), $F(1,62) = 13.68$, $p < .0001$, $\eta_p^2 = .18$, confirmed higher corrected R recognition in the TD compared to the ASD group, $p < .0001$, Cohen's $d = 1.14$, 95 % CI(0.60, 1.66). No between-group difference was found in corrected K recognition, $p = .21$, Cohen's $d = 0.31$, 95 % CI(-0.18, 0.80). A significant *Modality x Meaning* interaction (see Figure 2.3 right), $F(1,62) = 35.84$, $p < .0001$, $\eta_p^2 = .37$, demonstrated higher corrected recognition for meaningful pictures compared to meaningless shapes, $p < .0001$, Cohen's $d = 1.12$, 95 % CI(0.74, 1.48), with no effect of meaning on memory for words vs. non-words, $p = .24$, Cohen's $d = 0.18$, 95 % CI(-0.17, 0.53). A *Modality x R/K* interaction, $F(1,62) = 5.27$, $p < .05$, $\eta_p^2 = .08$, showed higher corrected R responses for visual compared to verbal materials, $p < .05$, Cohen's $d = 0.36$, 95 % CI(0.01, 0.71), and no difference between these materials for corrected K responses, $p = .66$, Cohen's $d = 0.05$, 95 % CI(0-0.29, 0.40). Finally, a significant three-way interaction of *Modality x Meaning x R/K*, $F(1,62) = 4.55$, $p < .05$, $\eta_p^2 = .07$, further qualified the interactions between these factors. Specifically, the effect of meaning on recognition performance was evident in corrected R responses in that meaningless non-words were slightly better recognised than meaningful words, $p = .08$, Cohen's $d = 0.26$, 95 % CI(-0.09, 0.61), whereas meaningful pictures were better recognised than meaningless shapes, $p < .0001$, Cohen's $d = 0.65$, 95 % CI(0.29, 1.00). Corrected K responses did not differ for verbal materials, $p = .51$, Cohen's $d = 0.11$, 95 % CI(-0.24, 0.45), but they were higher for meaningful pictures compared to meaningless shapes, $p < .0001$,

Cohen's $d = 0.62$, 95 % CI(0.26, 0.97). The absence of any additional interactions involving the Group factor, $F_{max} < 1.03$, $p_{min} > .31$, $\eta_{p\;max}^{2} < .02$, indicated that the attenuated levels of R but not K responses in the ASD group were persistent across meaningful and meaningless verbal and visual materials.

Table 2.4

Means and Standard Deviations for Hits, False Alarms (FAs), and Corrected recognition rates (Hits minus FAs) for recognition (total), Remember (R), and Know (K) responses for words, non-words, pictures and shapes for ASD and TD groups in Experiment 1.

	ASD			TD			Total		
	Total	**R**	**K**	**Total**	**R**	**K**	**Total**	**R**	**K**
	M	*M*	*M*	*M*	*M*	*M*	*M*	*M*	*M*
	(*SD*)	(*SD*)	(*SD*)	(*SD*)	(*SD*)	(*SD*)	(*SD*)	(*SD*)	(*SD*)
Hits									
Words	0.56	0.37	0.20	0.74	0.57	0.18	0.65	0.47	0.19
	(0.28)	(0.25)	(0.17)	(0.22)	(0.28)	(0.20)	(0.26)	(0.28)	(0.18)
Non-words	0.64	0.43	0.21	0.77	0.65	0.12	0.71	0.54	0.17
	(0.26)	(0.26)	(0.20)	(0.23)	(0.24)	(0.14)	(0.25)	(0.27)	(0.18)
Pictures	0.82	0.56	0.26	0.91	0.75	0.15	0.86	0.66	0.21
	(0.18)	(0.27)	(0.23)	(0.16)	(0.24)	(0.19)	(0.17)	(0.27)	(0.22)
Shapes	0.58	0.43	0.15	0.71	0.63	0.08	0.65	0.53	0.12
	(0.26)	(0.30)	(0.15)	(0.24)	(0.24)	(0.09)	(0.26)	(0.28)	(0.13)

	ASD			TD			Total		
	Total	**R**	**K**	**Total**	**R**	**K**	**Total**	**R**	**K**
	M	*M*	*M*	*M*	*M*	*M*	*M*	*M*	*M*
	(*SD*)	(*SD*)	(*SD*)	(*SD*)	(*SD*)	(*SD*)	(*SD*)	(*SD*)	(*SD*)
False Alarms									
Words	0.12	0.05	0.07	0.08	0.04	0.04	0.10	0.05	0.05
	(0.15)	(0.09)	(0.10)	(0.10)	(0.09)	(0.06)	(0.13)	(0.09)	(0.08)
Non-words	0.14	0.07	0.07	0.07	0.03	0.03	0.11	0.05	0.05
	(0.18)	(0.11)	(0.10)	(0.12)	(0.08)	(0.07)	(0.16)	(0.10)	(0.09)
Pictures	0.07	0.02	0.04	0.06	0.03	0.03	0.07	0.03	0.04
	(0.10)	(0.04)	(0.07)	(0.11)	(0.07)	(0.05)	(0.10)	(0.06)	(0.06)
Shapes	0.18	0.09	0.08	0.11	0.08	0.03	0.14	0.08	0.06
	(0.18)	(0.12)	(0.12)	(0.15)	(0.10)	(0.09)	(0.17)	(0.11)	(0.11)
Corrected recognition (Hits - False Alarms)									
Words	0.45	0.32	0.13	0.66	0.53	0.13	0.55	0.42	0.13
	(0.28)	(0.23)	(0.21)	(0.27)	(0.30)	(0.19)	(0.29)	(0.29)	(0.20)
Non-words	0.50	0.37	0.14	0.70	0.61	0.09	0.60	0.49	0.11
	(0.27)	(0.25)	(0.22)	(0.25)	(0.27)	(0.13)	(0.28)	(0.29)	(0.18)
Pictures	0.75	0.53	0.22	0.84	0.72	0.13	0.80	0.63	0.17
	(0.22)	(0.28)	(0.24)	(0.23)	(0.27)	(0.19)	(0.23)	(0.28)	(0.22)
Shapes	0.41	0.34	0.07	0.60	0.55	0.05	0.50	0.45	0.06
	(0.33)	(0.32)	(0.16)	(0.26)	(0.24)	(0.12)	(0.31)	(0.30)	(0.14)
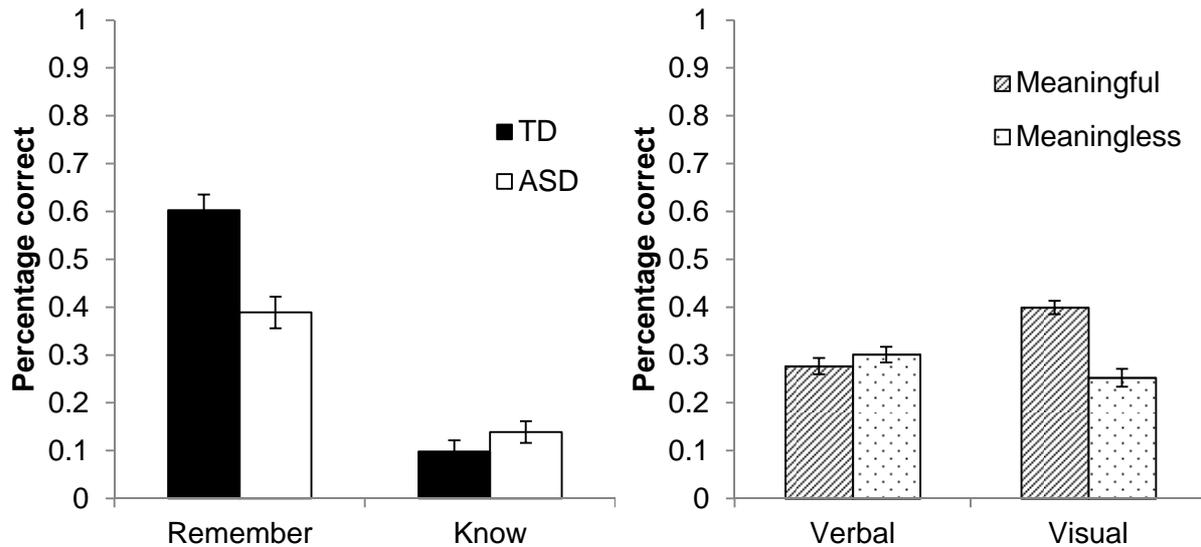
Figure 2.3. Displaying interactions for corrected recognition (Hits minus False Alarms) in Experiment 1. Left: Group x R/K interaction - Remember and Know collapsed across modalities and meaningfulness for ASD and TD groups. Right: Modality x Meaning interaction - rates for verbal and visual materials sorted according to meaningfulness collapsed across the two groups. The data are presented as mean ± SEM.

2.1.3.1.2 False Alarms

To examine whether the attenuated levels of R responses in the ASD group were the result of a more lenient response criterion, FAs (see Table 2.4) were analysed using a 2 (Group [ASD, TD]) x 2 (R/K [Remember, Know]) x 2 (Modality [verbal, visual]) x 2 (Meaning [meaningful, meaningless]) repeated measures ANOVA. This revealed a marginal main effect of *Group*, $F(1,62) = 3.65$, $p = .06$, Cohen's $d = 0.48$, 95 % CI(-0.02, 0.97), with higher FAs for the ASD compared to the TD group, as well as a significant main effect of *Meaning*, $F(1,62) = 6.51$, $p < .05$, Cohen's $d = 0.36$, 95 % CI(0.01, 0.71), with higher FAs for meaningless compared to meaningful materials. A significant *Modality x Meaning* interaction, $F(1,62) = 5.76$, $p < .05$, $\eta_p^2 = .09$, showed higher FAs for meaningless shapes compared to meaningful pictures, $p < .01$, Cohen's $d = 0.55$, 95 % CI(0.19, 0.90), but no effect of meaning on verbal materials, $p = .77$, Cohen's $d = -0.04$, 95 % CI(-0.39, 0.30). No

other main effects or interactions were significant, $F_{max} < 2.23$, $p_{min} > .14$, $\eta_{p\,max}^2 < .04$, including a Group x R/K interaction.

2.1.3.1.3 Sensitivity, response bias and goodness of fit of signal detection model

Slightly higher FAs for ASD individuals indicate difficulties in distinguishing old from new items. Therefore, potential differences between groups in response criteria were investigated further by calculating measures of sensitivity and response bias (Gaetano, Lancaster & Tindle, 2015) for the data presented in Table 2.4. Separate measures for sensitivity and response bias are needed as they are confounded in other measures such as Hits, FAs, and corrected recognition rates (Stanislaw & Todorov, 1999), and between-group differences may be caused by potential differences in sensitivity, response bias or both. A popular measure for sensitivity is d', which is, however, unaffected by response bias only if the d' assumptions are fulfilled, which cannot be tested in yes-no tasks (Stanislaw & Todorov, 1999). Therefore, the measure for sensitivity used here was A' (Pollack & Norman, 1964), as it is nonparametric and unaffected by response bias (Stanislaw & Todorov, 1999). A' values range from 0 (the participant confused response categories), through 0.5 (the participant did not distinguish between old and new items), to 1 (the participant distinguished perfectly between old and new unstudied items; Stanislaw & Todorov, 1999). Response bias was estimated by the nonparametric measure B" (Grier, 1971), which shows values ranging from -1 (a bias to say yes to all items), through 0 (indicating no response bias), to 1 (a bias to say no to all items; Stanislaw & Todorov, 1999). A' and B" were calculated for overall recognition and R rates using Hits and FAs to inspect the goodness of fit of the signal detection model to the data (see Bowler et al., 2000b; Gardiner & Gregg, 1997). A good fit is indicated by similar A' values derived from recognition as well as R data (Gardiner & Gregg, 1997), indicating that R and K respresent a unitary memory trace with stronger (R) and weaker (K) memories. A' has,

however, previously been reported as being higher for recognition compared to R responses, using the R/K recognition procedure, supporting a model postulating R and K as two separate processes (Gardiner & Gregg, 1997).

A' data (Table 2.5) were analysed with a 2 (Group [ASD, TD]) x 2 (Modality [verbal, visual]) x 2 (Meaning [meaningful, meaningless]) x 2 (Recognition/R [recognition, Remember]) repeated measures ANOVA, which showed significant main effects of *Group*, $F(1,62) = 17.01$, $p < .0001$, Cohen's $d = 1.03$, 95 % CI(0.50, 1.54), with higher A' rates for the TD compared to the ASD group, and *Meaning*, $F(1,62) = 10.32$, $p < .01$, Cohen's $d = 0.46$, 95 % CI(0.11, 0.81), with higher A' rates for meaningful compared to meaningless materials. There was also a significant *Modality x Meaning* interaction, $F(1,62) = 21.23$, $p < .0001$, $\eta_p^2 = .26$, with higher A' rates for meaningful pictures compared to meaningful words, $p < .0001$, Cohen's $d = 0.76$, 95 % CI(0.39, 1.11), and slightly higher A' rates for meaningless non-words compared to meaningless shapes, $p = .079$, Cohen's $d = 0.30$, 95 % CI(-0.05, 0.65). A marginally significant *Modality x Meaning x Recognition/R* interaction, $F(1,62) = 3.95$, $p = .05$, $\eta_p^2 = .06$, showed higher A' rates for meaningful pictures compared to meaningless shapes for both recognition and R rates, both $p < .0001$, Cohen's $d_{min} = 0.65$, 95 % CI(0.29, 1.00). No significant differences were found in A' rates for meaningful words as opposed to meaningless non-words in recognition and R rates, $p_{min} > .18$, Cohen's $d_{max} = 0.21$, 95 % CI$_{max}$(-0.14, 0.55). Most importantly, there was also a significant main effect of *RecognitionR*, $F(1,62) = 23.86$, $p < .0001$, Cohen's $d = 0.43$, 95 % CI(0.08, 0.78), with higher A' rates for recognition compared to R, indicating that the model did not fit the data well. No other main effects or interactions were significant, $F_{max} < 2.58$, $p_{min} > .11$, $\eta_p^2{}_{max} < .05$.

Table 2.5

Means and Standard Deviations for A' (sensitivity) and B" (response bias) for recognition and R responses for words, non-words, pictures, and shapes for ASD and TD groups in Experiment 1.

	ASD		TD		Total	
	Rec	**R**	**Rec**	**R**	**Rec**	**R**
	M (*SD*)	*M* (*SD*)	*M* (*SD*)	*M* (*SD*)	*M* (*SD*)	*M* (*SD*)
A'						
Words	0.81 (0.16)	0.78 (0.13)	0.89 (0.10)	0.86 (0.10)	0.85 (0.14)	0.82 (0.12)
Non-words	0.84 (0.12)	0.78 (0.15)	0.91 (0.10)	0.88 (0.12)	0.87 (0.12)	0.83 (0.14)
Pictures	0.93 (0.08)	0.86 (0.11)	0.95 (0.11)	0.92 (0.10)	0.94 (0.10)	0.89 (0.11)
Shapes	0.78 (0.18)	0.74 (0.21)	0.87 (0.14)	0.86 (0.13)	0.82 (0.17)	0.80 (0.18)
B"						
Words	0.37 (0.45)	0.49 (0.36)	0.34 (0.34)	0.58 (0.25)	0.36 (0.40)	0.53 (0.31)
Non-words	0.28 (0.46)	0.47 (0.34)	0.33 (0.46)	0.55 (0.37)	0.31 (0.46)	0.51 (0.35)
Pictures	0.24 (0.43)	0.59 (0.26)	0.06 (0.41)	0.43 (0.39)	0.15 (0.42)	0.51 (0.34)
Shapes	0.24 (0.37)	0.37 (0.36)	0.31 (0.45)	0.48 (0.33)	0.28 (0.41)	0.43 (0.35)

A 2 (Group [ASD, TD]) x 2 (Modality [verbal, visual]) x 2 (Meaning [meaningful, meaningless]) x 2 (Recognition/R [recognition, Remember]) repeated measures ANOVA of B" data (Table 2.5) showed a significant main effect of *Modality*, $F(1,62) = 4.72$, $p < .05$, Cohen's $d = 0.32$, 95 % CI(-0.03, 0.67), with higher B" rates for verbal compared to visual materials, as well as a significant *Group* x *Meaning* interaction, $F(1,62) = 4.09$, $p < .05$, $\eta_p^2 = .06$, with a trend for higher B" rates for meaningless compared to meaningful materials for the TD group, but meaningful compared to meaningless materials for the ASD group, both n.s., $p_{max} = .21$, Cohen's $d_{min} = 0.25$, 95 % CI(-0.24, 0.74). Again the main effect of

Recognition/R was significant, $F(1,62) = 59.36$, $p < .0001$, Cohen's $d = 0.92$, 95 % CI(0.55, 1.27), showing higher B" rates for R compared to recognition. The effect was further qualified by a significant *Meaning x Recognition/R* interaction, $F(1,62) = 5.73$, $p < .05$, $\eta_p^2 = .09$, which showed a trend for higher B" rates for meaningful compared to meaningless R rates, $p = .14$, Cohen's $d = 0.21$, 95 % CI(-0.14, 0.56), which was not evident in recognition rates, $p = .40$, Cohen's $d = 0.12$, 95 % CI(-0.23, 0.47). Finally, a significant *Modality x Meaning x Recognition/R*, $F(1,62) = 7.34$, $p < .01$, $\eta_p^2 = .11$, indicated higher B" rates for meaningful words compared to meaningful pictures for recognition rates, $p < .01$, Cohen's $d = 0.50$, 95 % CI(0.15, 0.85), but not R rates, $p = .63$, Cohen's $d = 0.07$, 95 % CI(-0.27, 0.42). No other main effects or interactions were significant, $F_{max} < 2.47$, $p_{min} > .12$, $\eta_p^2{}_{max} < .04$.

2.1.3.1.4 Episodic memory in R justifications

Participants' justifications for R responses were tape-recorded, transcribed and classified according to the kind of statements that were produced. All participants provided detailed justifications for all R responses, and it was of interest to inspect the quality of R justifications. One logical way of coding was to inspect the number of associations participants formed with information from the immediate study episode and information relating to general knowledge or personal experiences that had not directly been part of the study. Therefore, statements were categorised into two groups - things that happened *within* the actual study episode (item characteristics, e.g., "I remember this because it was just one sock.", or study episode, e.g., "I pictured the word in my head."), and information from *outside* the study episode that the participant had related to the actual items (semantic knowledge, e.g., "I remembered the apple because it is a fruit.", or personal experiences, e.g., "I had a sandwich for lunch."). A second independent rater, who was blind to the predictions and groups, and who had been trained on these criteria, scored the transcripts of eight randomly selected participants (four from each group). The strength of the inter-rater

agreement between the scorings of the author of this thesis and the second rater, calculated with Cohen's kappa, was very good, $\kappa = .827$, $p < .0001$, showing that the aforementioned scheme can be coded reliably.

The data (see Figure 2.4) were analysed using a 2 (Group [ASD, TD]) x 2 (Type of EM statements [inside, outside]) repeated measures ANOVA. The analysis showed significant main effects of *Group*, $F(1,62) = 16.76$, $p < .0001$, Cohen's $d = 1.02$, 95 % CI(0.49, 1.53), with a higher number of EM statements for the TD compared to the ASD group, and *Type of EM statements*, $F(1,62) = 8.97$, $p < .01$, Cohen's $d = 0.62$, 95 % CI(0.26, 0.97), with more statements referring to information from outside compared to within the study episode. A significant *Group x Type of EM statements* interaction, $F(1,62) = 4.50$, $p < .05$, $\eta_p^2 = .07$, showed more EM statements from outside the study episode for the TD ($M = 16.50$, $SD = 8.06$) compared to the ASD group ($M = 9.63$, $SD = 6.96$), $p < .01$, Cohen's $d = 0.91$, 95 % CI(0.39, 1.42), but a similar number of EM statements from inside the study episode for both groups ($M_{TD} = 9.38$, $SD_{TD} = 5.88$; $M_{ASD} = 8.41$, $SD_{ASD} = 5.90$), $p = .51$, Cohen's $d = 0.16$, 95 % CI(-0.33, 0.65).
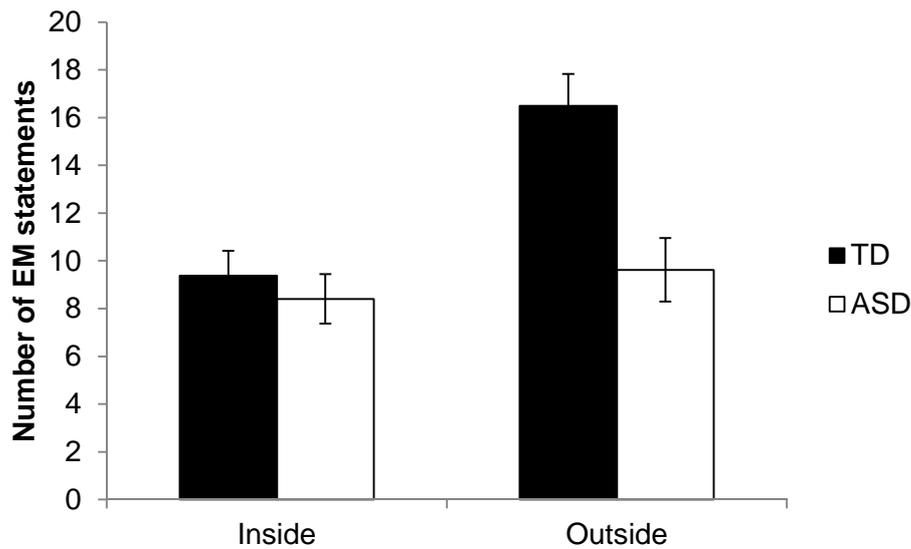
Figure 2.4. Number of EM statements referring to information from within (inside) and from outside the study episode, reported as justifications for Remember responses in ASD and TD groups in Experiment 1. The data are presented as mean ± SEM.

2.1.3.1.5   Exploratory regression analyses regarding the effects of age

First, bivariate correlations were run (see Table 2.6), which showed no significant correlations between R or K responses and age.

Table 2.6

Bivariate correlations between corrected recognition for Remember and Know responses and age for the participants in Experiment 1.

	Remember	**Know**
age	-.05	.21

Note. *significant at $p < .05$. **significant at $p \leq .01$.

It was, however, possible that the correlation coefficients were affected by a third variable that may have influenced the relationship between R responses and age (Bewick, Cheek & Ball, 2003), and this variable may have been group, in that age may have had a different

effect on memory in the two groups. Therefore, second, multiple linear regression analyses were performed, including Age and a Group x Age interaction term, to predict behavioural memory performance. The Group x Age interaction term explained 23.1 % of the total variance, $R^2 = .23$, $F(1,62) = 18.57$, $p = .00$, and it significantly predicted corrected R recognition, $\beta = -.48$, 95 % CI(-0.01, 0.00), $p < .0001$. Visual inspection of Figure 2.5 and the regression coefficients showed that age was a better predictor of R responses in the TD as opposed to the ASD group. Neither Age nor a Group x Age interaction term explained any variance in corrected K recognition.
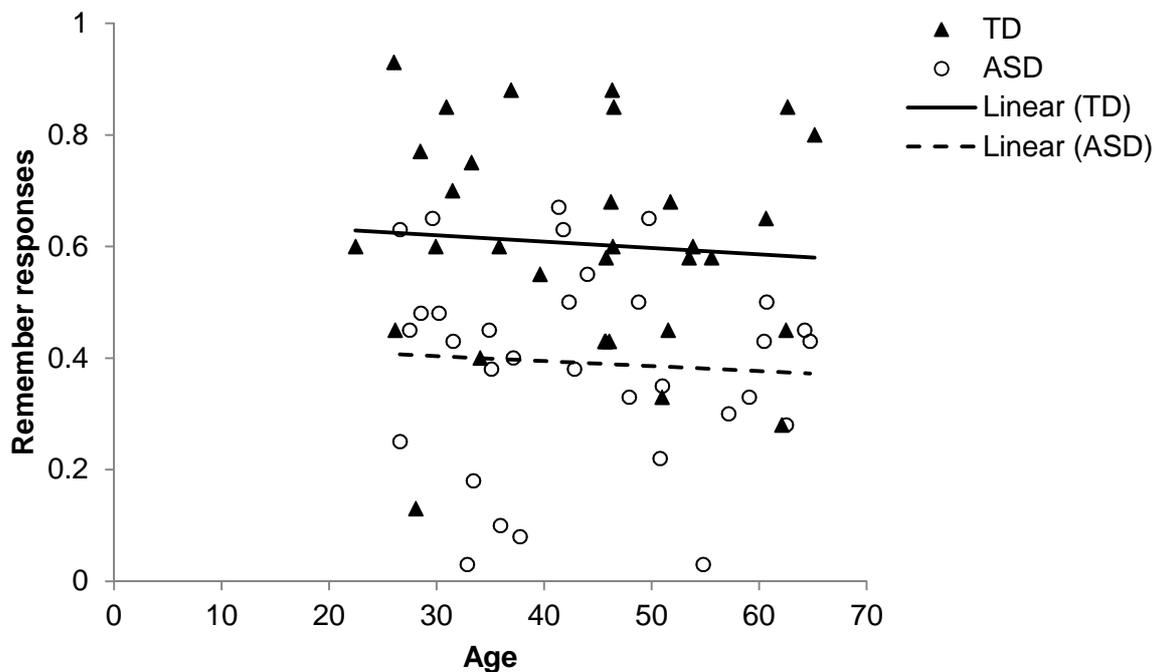
Figure 2.5. The relationship between age and corrected recognition in Remember responses in Experiment 1, showing a stronger age-related difference in Remember responses in TD compared to ASD participants.

2.1.3.2 Pupillometry measures

2.1.3.2.1 Baseline pupil size

Since there were no previous investigations of baseline pupil size in adults with ASD, it was first established whether findings of the current study were in line with the baseline pupil size data in ASD children presented above. No significant between-group differences in baseline pupil size were found in the current study (see Table 2.2).

2.1.3.2.2 Pupil Old/New effect at retrieval

An Old/New comparison can only be undertaken for the retrieval phase of this experiment, because all items presented at study (encoding) were new to the participants and only at test (retrieval), previously presented (Old) items were intermixed with previously unseen (New) items. The data presented in Table 2.7 and Figure 2.6 were analysed with a 2 (Group [ASD, TD]) x 2 (Modality [verbal, visual]) x 2 (Meaning [meaningful, meaningless]) x 2 (Set [Old, New]) repeated measures ANOVA. Significant main effects of *Modality*, $F(1,55) = 6.79$, $p < .05$, Cohen's $d = 0.22$, 95 % CI(-0.15, 0.59), *Meaning*, $F(1,55) = 11.94$, $p < .01$, Cohen's $d = 0.28$, 95 % CI(-0.09, 0.65), and *Set*, $F(1,55) = 10.53$, $p < .01$, Cohen's $d = 0.22$, 95 % CI(-0.15, 0.59), showed larger pupils for verbal compared to visual materials, for meaningful compared to meaningless materials, and for old compared to new items. A significant *Group x Set* interaction, $F(1,55) = 5.12$, $p < .05$, $\eta_p^2 = .09$, indicated larger pupils for old compared to new items for the TD group, $p < .0001$, Cohen's $d = 0.38$, 95 % CI(-0.14, 0.88), but similar pupil sizes for old and new items for the ASD group, $p = .50$, Cohen's $d = 0.07$, 95 % CI(-0.47, 0.60). No other main effects or interactions were significant, $F_{max} < 2.65$, $p_{min} > .10$, $\eta_{p\ max}^2 < .05$.

Table 2.7

Means and Standard Deviations for maximum pupil dilation ratio (pupil size during task/pupil size during baseline) for Old (studied) and New (unstudied) words, non-words, pictures, and shapes for ASD and TD groups in Experiment 1.

	ASD		TD		Total	
	Old	**New**	**Old**	**New**	**Old**	**New**
	M (*SD*)	*M* (*SD*)	*M* (*SD*)	*M* (*SD*)	*M* (*SD*)	*M* (*SD*)
Words	1.06 (0.10)	1.05 (0.08)	1.07 (0.11)	1.06 (0.13)	1.07 (0.10)	1.05 (0.11)
Non-words	1.04 (0.06)	1.03 (0.10)	1.04 (0.06)	1.02 (0.05)	1.04 (0.06)	1.03 (0.08)
Pictures	1.03 (0.05)	1.03 (0.07)	1.07 (0.09)	1.03 (0.08)	1.05 (0.08)	1.03 (0.07)
Shapes	1.03 (0.04)	1.03 (0.06)	1.04 (0.06)	1.01 (0.05)	1.03 (0.05)	1.02 (0.06)
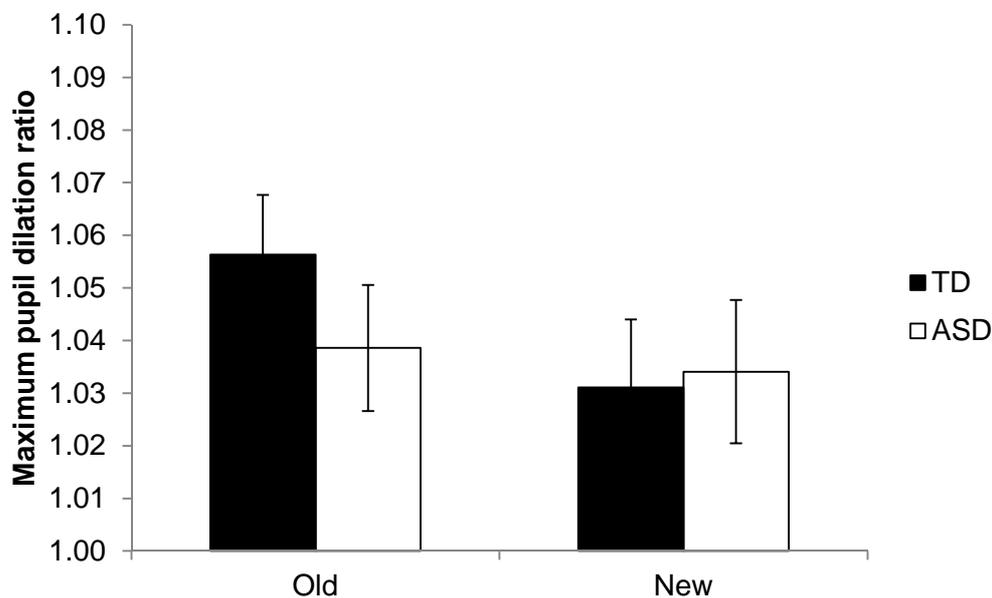
Figure 2.6. Group x Set interaction displaying the maximum pupil dilation ratio (pupil size during task/pupil size during baseline) for Old (studied) and New (unstudied) items collapsed across modalities and meaningfulness for ASD and TD groups in Experiment 1. The data are presented as mean ± SEM.

2.1.3.2.3 Pupil Old/New effect at retrieval - behavioural accuracy

2.1.3.2.3.1 Correct responses

To investigate whether the pupil Old/New effect was related to the memory findings presented above, pupil size data were sorted according to behavioural response accuracy. Because not all participants had made mistakes for all materials, the data were collapsed across materials and were analysed separately for correct and incorrect responses for old and new items. Correct responses for old (Hits) and new (CR) items (see Figure 2.7) were compared with a 2 (Group [ASD, TD]) x 2 (Answer type [Hit, CR]) repeated measures ANOVA. A significant main effect of *Answer type*, $F(1,55) = 10.42$, $p < .01$, Cohen's $d = 0.29$, 95 % CI(-0.08, 0.66), showed larger pupils for Hits (old items) compared to CRs (new items), and a marginal *Group x Answer type* interaction, $F(1,55) = 3.96$, $p = .05$, $\eta_p^2 = .07$, indicated that this was only the case for the TD group ($M_{Hit} = 1.06$, $SD_{Hit} = 0.08$; $M_{CR} = 1.03$, $SD_{CR} = 0.06$), $p < .0001$, Cohen's $d = 0.47$, 95 % CI(-0.05, 0.98), but not the ASD group ($M_{Hit} = 1.04$, $SD_{Hit} = 0.04$; $M_{CR} = 1.03$, $SD_{CR} = 0.07$), $p = .40$, Cohen's $d = 0.11$, 95 % CI(-0.42, 0.64). There was no main effect of *Group*, $F(1,55) = 0.28$, $p = .60$, Cohen's $d = 0.14$, 95 % CI(-0.38, 0.66).
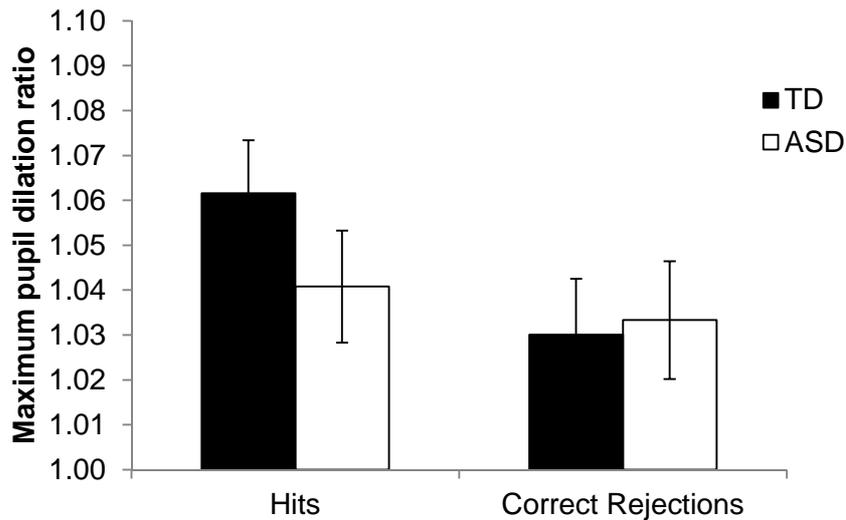
Figure 2.7. Maximum pupil dilation ratio (pupil size during task/pupil size during baseline) for Hits (correctly identified old items) and Correct Rejections (correctly rejected new items) collapsed across the materials for ASD and TD groups in Experiment 1. The data are presented as mean ± SEM.

2.1.3.2.3.2   Incorrect responses

A 2 (Group [ASD, TD]) x 2 (Answer type [Miss, FA]) repeated measures ANOVA comparing incorrect responses for old (Misses) and new items (FAs; see Figure 2.8) showed no significant main effects or interactions, $F_{max} < 0.44$, $p_{min} > .51$, $\eta_p^2{}_{max} < .02$.
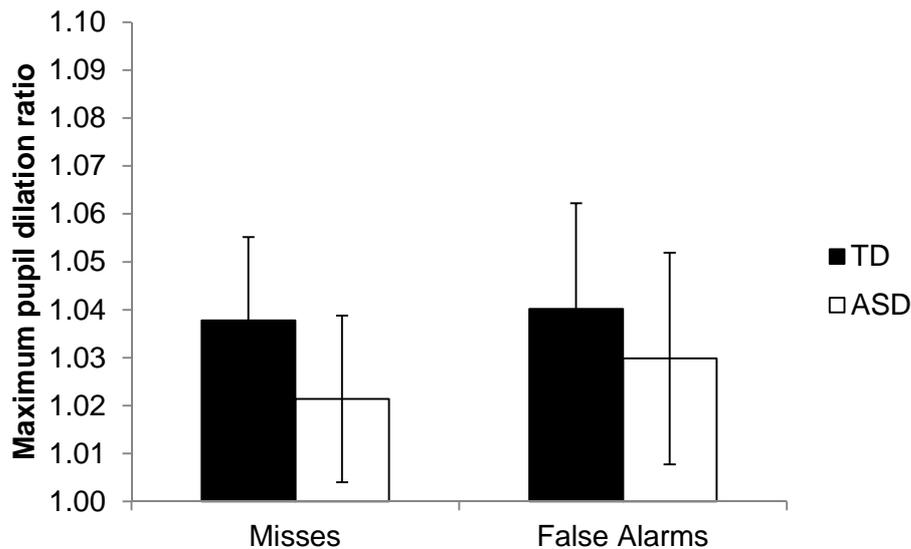
Figure 2.8. Maximum pupil dilation ratio (pupil size during task/pupil size during baseline) for Misses (incorrectly rejected old items) and False Alarms (incorrectly accepted new items) collapsed across materials for ASD and TD groups in Experiment 1. The data are presented as mean $\pm$ SEM.

2.1.3.2.4 Pupil effects at encoding - behavioural accuracy

Since it is possible that between-group differences for later correctly and incorrectly remembered items may have already existed at study, it was of interest to set pupil size at encoding in relation to later response accuracy. Avoiding a loss of data resulting from ceiling performance, the data were collapsed across materials (see Figure 2.9) and were analysed with a 2 (Group [ASD, TD]) x 2 (Accuracy [Correct, Incorrect]) repeated measures ANOVA, which showed no significant main effects or interactions, $F_{max} < 1.35$, $p_{min} > .25$, $\eta_p^2{}_{max} < .03$.
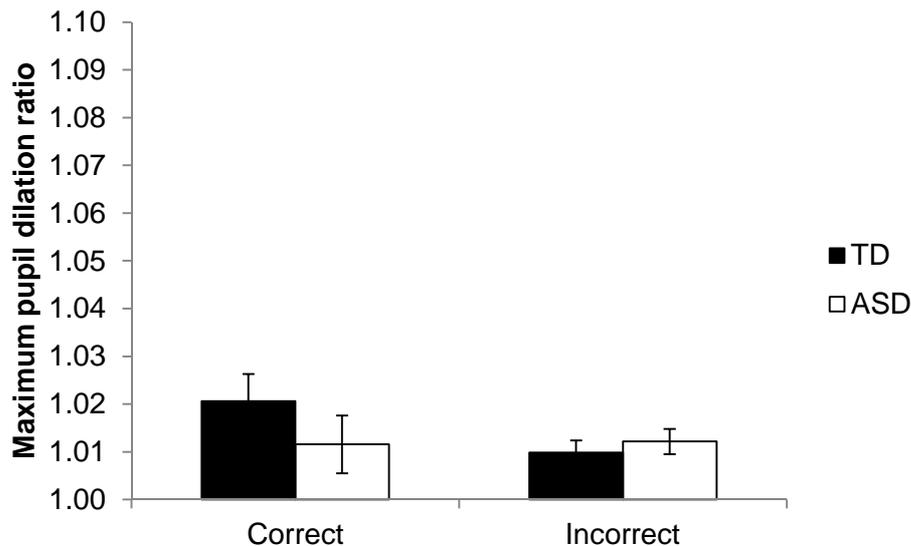
Figure 2.9. Maximum pupil dilation ratio (pupil size during task/pupil size during baseline) for encoding data collapsed across materials and split up by later correct and incorrect behavioural responses for ASD and TD groups in Experiment 1. The data are presented as mean ± SEM.

2.1.3.3   Correlations among behavioural memory and pupil size data

To confirm that the pupil Old/New effect at retrieval reflects a memory phenomenon, pupil data were set in relation to behavioural memory data. Bivariate correlations were run between a difference score of pupil size to old and new items and corrected recognition accuracy collapsed across all four material types (Table 2.8). There were no significant correlations between the two variables. Visual inspection of the data, however, showed that there were two outliers (one ASD, one TD individual) in the pupil size data, who showed a strongly negative pupil Old/New ratio, which was contrary to predictions and unlike the difference scores in all other participants. In both cases, the pupil Old/New ratio was more than 3 SDs below the group mean. It is possible that in these two individuals there may still have been some noise in the data or that their pupil Old/New effect may have just been unusual. Excluding these two individuals did not change the results of the analyses reported above, but

it led to a strongly significantly positive correlation between behavioural memory accuracy and the pupil Old/New difference (see Table 2.8), especially for ASD individuals, suggesting that the larger the pupil response to old as opposed to new items was at retrieval, the higher were participants' corrected recognition scores (see Figure 2.10), confirming that the pupil Old/New effect reflects a real memory phenomenon.

Table 2.8

Bivariate correlations between behavioural corrected recognition accuracy and a difference score of pupil size in response to previously studied (Old) and unstudied (New) items in Experiment 1.

	Pupil Old/New	Pupil Old/New[a]	Pupil Old/New$_{TD}$	Pupil Old/New$_{ASD}$
Corrected recognition	.16	.36**	.02	.52**

Note. [a]Pupil size Old/New difference after the exclusion of one ASD and one TD outlier.

*significant at $p < .05$. **significant at $p \leq .01$.
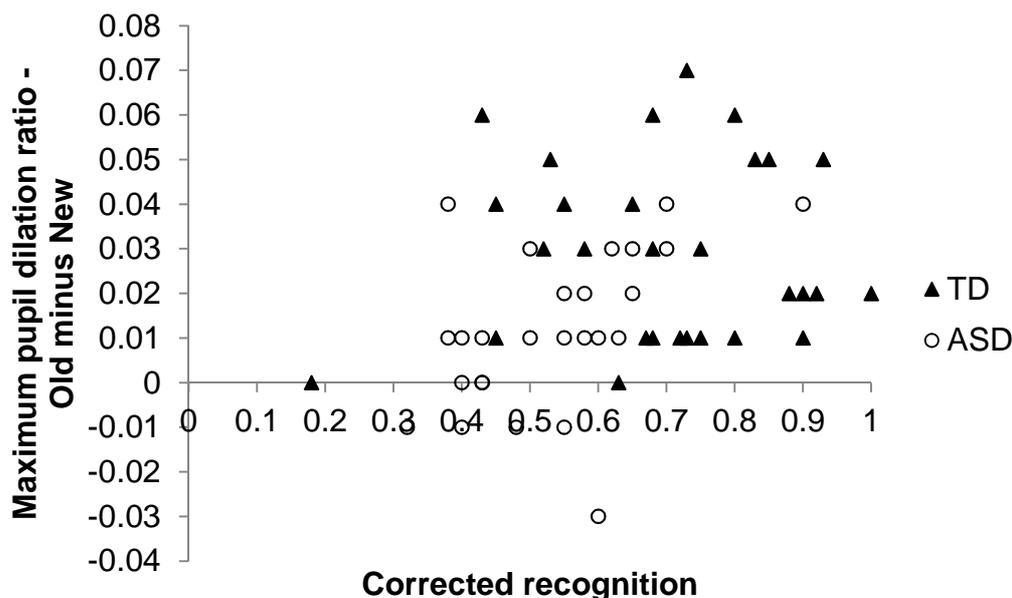
Figure 2.10. Association between corrected recognition rates and the maximum pupil dilation ratio (pupil size during task/pupil size during baseline) between old and new items. The correlation illustrates that larger pupils in response to old vs. new items was related higher corrected recognition rates in the behavioural response.

2.1.4 Discussion

The aim of this study was to compare, systematically, R and K responses for different materials in adults with and without ASD, manipulating the factors of modality and meaning, and to examine the criteria, which both groups base their recognition decisions on. Pupillometry was used, in addition to behavioural memory measures, to see if results would be replicated with measures acting outside conscious awareness and to investigate whether it would be possible to devise measures that would, in principle, be suitable for the study of memory in minimally verbal and/or preverbal individuals with ASD. Finally, preliminary analyses were run to investigate the effect of age on recognition memory in both groups.

Using the R/K recognition memory procedure, participants were asked to indicate which of 20 words, pictures, non-words, and shapes (half of which had been presented at

study) they had seen previously, and to specify whether or not they remembered any contextual details about previously studied items. For the behavioural results, it was predicted that both groups would produce more R compared to K responses, but that R rates would be attenuated for ASD compared to TD participants. It was also predicted that ASD adults would show lower overall corrected recognition, that both groups would remember pictures better than words, and that they would perform better on meaningful as opposed to meaningless stimuli. Interactions between modality, meaning, and R/K were predicted to be similar for both groups. It was predicted that ASD individuals would show higher FA rates, lower sensitivity, and higher response bias, and that their verbal R justifications would be restricted to information from the study episode. Most of these predictions were confirmed, and results will be discussed in the next few paragraphs, which will be followed by a discussion of the pupillometry findings.

As predicted, both groups showed significantly higher R compared to K rates, and R rates were lower for ASD compared to TD individuals, confirming previous findings of reduced episodic and intact semantic memory in ASD (see Section 1.4.1.2 and Bowler et al., 2000a & b; 2007; Bowler & Ring, in preparation; Massand, 2011; Mayer et al., 2014; Souchay et al., 2013; Tanweer et al., 2010; Gaigg et al., 2015). This conclusion was further supported by higher A' rates for recognition compared to R responses for both groups, which support dual-process models of recognition memory (Gardiner & Gregg, 1997; see Section 1.3.2 and the information presented earlier in this chapter). Also in line with predictions, ASD participants showed lower overall corrected recognition compared to the TD group (Bowler et al., 2004; Bowler & Ring, in preparation; Souchay et al., 2013; Tanweer et al., 2010). The Group x R/K interaction showed that this overall reduction in corrected recognition in ASD resulted from a selective impairment in R responses, leaving K responses in ASD intact. These data suggest particular difficulties with the retrieval of relational

information in ASD (Bowler et al., 2011), since R responses require remembering the items as well as the context of their presentation. Looking at justifications for R responses, ASD adults struggled, in particular, with relating study material to contextual information from outside the immediate context of the experiment, while they showed less difficulty in relating study materials to contextual details from within the study episode. This finding may, potentially, help to clarify why R deficits in ASD have not been replicated consistently across all studies. For example, in some studies ASD individuals may have formed more relations with details from outside the immediate study episode, or TD individuals may have related more items to the immediate study context. A possible follow-up study of the current finding of lower relations between items and context from outside the experiment in ASD would be to compare ASD and TD groups by using the R/K recognition procedure, specifically, manipulating the extent to which participants need to relate the study material to extra- or intra-experimental details to clarify whether and to what extent a R deficit in ASD exists if both groups are asked to justify their R responses with contextual details from within the study episode. Previous inconsistent results may have also been caused by insufficient sample sizes, not detecting smaller differences between groups in R responses and corrected recognition rates. This idea is supported by medium to large effect sizes for between-group differences in previous R/K investigations in ASD (e.g., Bowler et al., 2000b; Massand, 2011). Differences between findings may also be related to the task instructions. Whereas participants were instructed to say 'no' when they were unsure if they had studied an item in the current study, in other studies participants may have confused unstudied with familiar materials, leading to increased K judgements. This interpretation is in line with higher Guess (Gaigg et al., 2015) or K rates for ASD compared to TD individuals in previous R/K studies (Bowler et al., 2000a; 2007), and between-group differences in ERP data for K responses that reflected increased Guess rates within K responses in the ASD group (Massand, 2011).

Difficulties in distinguishing old and new items in ASD in the current study were also evident in terms of somewhat higher FA rates, as well as lower sensitivity. This finding is in line with research on memory illusions, where ASD individuals have reported seeing more lure words that were orthographically related to the studied words compared to the TD group, especially when words were emotionally arousing (Gaigg & Bowler, 2009). More intrusion errors have also been reported in the free recall of words in ASD individuals (e.g., Bowler et al., 2000b; 2008a; Tager-Flusberg, 1991). Taken together, these results suggest some level of confabulation in ASD, which may be related to a problem with metacognition in terms of response monitoring. Difficulties in this area in ASD have been reported previously (Grainger et al., 2014; Wilkinson, Best, Minshew & Strauss, 2010; Wojcik et al., 2013).

Regarding the behavioural manipulations, both groups remembered visual materials better than verbal materials, confirming the *picture superiority effect* (Shepard, 1967). This was especially true for meaningful materials. A picture superiority may also explain previous inconsistent results, for example, lower rates of illusory memory in ASD, when participants were asked to memorise geometric shapes (Hillier, Campbell, Keillor, Philllips & Beversdorf, 2007). These results also indicate that pictorial materials are easier to remember for persons with ASD.

In line with predictions, both groups remembered meaningful materials better than meaningless materials, indicating that both groups found it easier to use meaning inherent in the study materials rather than to establish meaning for the materials themselves. Against predictions, but in line with Ameli et al. (1988), and like TD individuals, ASD individuals showed particular difficulties remembering meaningless materials, demonstrating an advantage for meaningful materials also in ASD in the current study. R justifications in the current study gave a hint that difficulties in R in ASD were not generally related to the use of meaning inherent in the study materials, but that they were related, specifically, to

establishing links to information from outside the actual study episode. This finding confirms previous ideas that ASD individuals save every episode separately, leading to reduced generalisation of individual experiences and reduced transfer of information across situations in ASD (see Sections 1.2.5, 1.4.2.5.4; Plaisted et al., 1998a; Swettenham, 1996). Overall, the behavioural memory data indicate that R difficulties in ASD are not specific to aspects of language in that they expand to visual and non-meaningful materials, and that they are of a more general nature, hinting at problems with relational processing in ASD (Bowler et al., 2011).

Considering the exploratory investigation of the influence of age on corrected recognition, in line with predictions, no effect of age on K responses was found for either group. However, age had a differential effect on R responses in the two groups, in that a stronger age-related memory difference was found for TD as opposed to ASD individuals. This finding is in line with the *safeguard hypothesis* (Geurts & Vissers, 2012), and a recent study reporting reduced effects of age on visual memory in large ASD compared to TD samples (Lever & Geurts, 2016). It is important to note, however, that ASD individuals were at a lower performance level in younger years as compared to TD individuals, therefore, supporting the ageing analogy of autistic memory (Bowler, 2007).

Regarding the pupillometry data, it was expected that TD individuals would show the pupil Old/New effect with larger pupils for previously studied compared to unstudied items, and that the ASD data would be characterised by an increase or a reduction of this effect. Before looking at this effect, it was of interest to establish whether increased baseline pupil sizes found for ASD children (C. J. Anderson & Colombo, 2009; Blaser et al., 2014) were also apparent in the adult data. This was not the case. Baseline pupil sizes were similar in both adult groups in the current study, finding no support for an increased activity of the autonomic nervous system in ASD adults. It is possible that ASD children show a difference

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in baseline pupil size that disappears in later ages. However, inconsistencies in the findings may also be related to "real" variability between different groups of participants. The latter idea is supported by inconsistencies in findings using other indicators of the functionality of the autonomic nervous system in ASD (for a review see Nuske et al., 2014a). Differences in findings between studies may also be caused by different materials used, or by movement artefacts, affecting pupil size measurements that are better controlled in some studies as opposed to others (Nuske et al., 2014a). An advantage of the current study is the large sample size, which took care of some variability in the data. However, more research is needed to clarify if the findings will be replicated.

Predictions regarding the pupil Old/New effect were confirmed. TD individuals showed larger pupils for old compared to new items for all materials and for correct responses, which is in line with a growing body of literature (Gomes et al., 2015; Heaver & Hutton, 2011; Montefinese et al., 2013; Otero et al., 2011; Papesh et al., 2012; Võ et al., 2008). In contrast, ASD individuals showed similar pupil sizes for old and new items, suggesting that, physiologically, ASD individuals did not distinguish between old and new items. This finding fits with the behavioural memory data, showing higher FAs and lower sensitivity. Correlations between the pupil Old/New effect and behavioural memory accuracy suggest that the pupil Old/New effect reflects a real memory phenomenon, and they highlight the potential for its use in broader ASD populations with more limited verbal and/or intellectual abilities. It is important to note that the significant difference in luminance between meaningful pictures and meaningless shape stimuli may have confounded the data. However, since verbal materials were well-matched in terms of luminance and other criteria, such as numbers of letters and syllables, materials were presented in blocks of the same material type, and since the data were analysed ignoring the first item in every block, it seems unlikely that these luminance differences affected the main finding of the pupil Old/New

difference. Because of the lack of previous findings on pupil size relating to memory in ASD, and in other psychological disorders, the current findings leave considerable room for speculation.

In line with ERP studies that found a difference in memory-specific neurophysiological activation between ASD and TD groups, as well as an absence of prominent ERP Old/New effects known from the TD literature for ASD individuals (Massand et al., 2013; Massand & Bowler, 2015), the current findings suggest a different underlying physiology for recognition memory in ASD. Massand et al. (2013) concluded from their findings that episodic and semantic memory in ASD may be driven neurologically by a single system rather than two different systems as in TD individuals. In line with findings of reduced pupilliary responsiveness to emotion in ASD (Nuske et al., 2014b & c), the current findings suggest that differences in emotion and memory are signs of a more domain general difference in ASD.

In a more general context, the lack of a pupil Old/New effect in ASD can be interpreted in various ways. First, it may have been caused by a lack of interest in the materials as pupillometry has been shown to be an indicator of interest in pictures, food, taste, and music (Sirois & Brisson, 2014). In addition, anecdotal evidence suggested that autistic people's memory is guided by interest and what they are not interested in, they do not remember. This is, however, highly speculative as research to demonstrate this remains to be carried out. It seems also a rather unlikely explanation given that ASD participants, behaviourally, recognised the studied materials in the current study well above chance. Since changes in pupil size have also been suggested to be an indicator of cognitive effort (Van Gerven, Paas, Van Merriënboer & Schmidt, 2004) – recollection is more cognitively demanding, a lack of a difference in pupil size between old and new items may indicate that identifying an old item as old and a new item as new was similarly effortful or effortless for

individuals with ASD. Pupil size is also seen as an indicator of memory strength, in that stronger memories were related to higher peaks in pupil size (Papesh et al., 2012). Therefore, another possibility is that a reduced pupil size for old items in ASD indicates weaker memories. This idea is supported by slightly higher FAs and lower sensitivity in ASD in the current study, as well as findings from other studies, such as higher K rates in R/K recognition tests (Bowler et al., 2000a; 2007), more intrusion errors in free recall tests (e.g., Bennetto et al., 1996; Bowler et al., 2000b; 2008a; Minshew & Goldstein, 1993; Kamio & Toichi, 2007), and sometimes more memory illusions for ASD compared to matched TD participants (e.g., Gaigg & Bowler, 2009), indicating difficulties to distinguish studied from lure items in ASD. Physiologically, pupil responses are controlled by the locus coeruleus, which is related to the hippocampus via noradrenergic transmissions and it, therefore, either inhibits or enhances hippocampal functions (Amaral & Sinnamon, 1977), having an important role for long-term memory consolidation and retrieval shortly after study (Sara, 2009). Finally, a lack of a difference in pupil size between old and new items may also be an indicator of an information overload, apparent through a "levelling" of the pupil size, leading to task disengagement. Pupil size levelling becomes apparent in the current study, when inspecting Figure 2.6. Unlike amnesic patients showing an increased pupil size for new compared to old items (Laeng et al., 2007), ASD individuals in the current study showed a decreased pupil size for old items, which was similar to the size for new items. This reduction of a pupil response has been observed previously in working memory tasks with higher processing load in patients with schizophrenia (Granholm, Morris, Sarkin, Asarnow & Jeste, 1997), as well as TD OA (Van Gerven et al., 2004), which further supports the *ageing analogy* of autistic people's memory (Bowler, 2007). A possible pathway for the lack of a pupil size Old/New difference in ASD would be that task disengagement following overload would lead to poorer encoding, ultimately producing weaker memories and, thereby, making

it harder for ASD participants to distinguish between old and new items at test. Task disengagement would be caused by lower norepinephrine concentrations (Hoffing & Seitz, 2015), having downstream effects, such as poor organisation of the study materials (Southwick et al., 2011). Next to the locus coeruleus releasing norepinephrine (Goldinger & Papesh, 2012), another brain region to investigate further in ASD would be the perirhinal cortex underlying the pupil novelty response described above, observed in amnesic patients (Laeng et al., 2007). A lack of such a novelty preference in the ASD individuals in the current study may indicate that the perirhinal cortex works differently in this group.

Drawing together, the current study showed that the pupil Old/New effect at retrieval is a useful measure for the study of the underlying physiology in memory in ASD. The common pupil Old/New effect for TD individuals was replicated and differential pupil sizes for meaningful and meaningless materials for both groups replicated behavioural effects of the manipulations and indicated that meaningful results were established with this new technique. In addition, these findings extended previous research on the pupil Old/New effect, suggesting that verbal and meaningful materials may be more distinct and, therefore, easier to remember, even without conscious awareness. Most importantly, correlations between behavioural memory and pupil size data indicated that the pupil Old/New effect reflects a real memory phenomenon. Following this demonstration of the usefulness of this measure, future research should adapt a pupil size paradigm for less verbal ASD individuals. In a more general context, the absence of a pupil Old/New effect may be a potential candidate for a biomarker for ASD in that a clearly atypical pupil Old/New effect was found that was universal for different types of materials. A biomarker would in this case be defined as an objectively measurable indicator of a pathogenic process (NIH Biomarker Definitions Working Group, 2001). Further demonstrations of this effect in other ASD populations with various cognitive and/or intellectual abilities are needed, to establish if the absence of a pupil

Old/New effect in ASD can really function as a biomarker. In addition, future research should compare, systematically, pupil responses for individuals with different disorders, such as ASD and schizophrenia or amnesia, to find out if the absence of a pupil Old/New effect can be established as something specific and unique to ASD. Cross-disorder research to establish the full variation of processes such as cognition is one of the aims of the Research Domain Criteria debate (Cuthbert & Insel, 2013).

In conclusion, the behavioural memory data broadly replicate previous research by showing that the EM impairment in ASD is universal across different materials, and that ASD individuals demonstrate clear difficulties in remembering contextual information and, therefore, relational binding. With a R/K paradigm a special type of EM and context is tested, i.e., memory for subjective context, because the participant can choose which context information to remember. The question arises whether remembering a specific type of context such as locations for objects on a computer screen is also difficult for ASD individuals. What follows on from this is the need for systematic investigations of different forms of relational memory in ASD to see which one is most difficult and to increase generalisability of the findings by using other more rarely used materials rather than verbal materials. These investigations of relational memory will be presented in the next chapter in Experiments 2 and 3.

3 Chapter 3: Relational memory

3.1 Experiment 2: Object-location memory

3.1.1 Introduction

3.1.1.1 Theoretical background

Previous research (see Section 1.4.1) and Experiment 1 have shown particular difficulties in EM in ASD. EM can be distinguished into *item* memory – the memory for single units of material with one meaning (Cohen et al., 1997) – and *relational* memory – the memory for context information or relations among these items (Davachi, 2006) – previously presented in Section 1.3.2. Mostly, previous research has demonstrated intact item memory in ASD. Item memory difficulties become apparent in ASD in tasks specifically probing relational processing such as in Experiment 1, where reduced memory for context information (R responses) led to a decrease in item memory. Reduced memory performance in ASD can also occur, when it is helpful to organise materials in a certain way, or when it is beneficial to use meaning to relate these materials (Section 1.4.1.3). In line with this idea, ASD participants' task performance typically benefits from support to organise or retrieve materials (see Section 1.4.1.3). In relational memory, such as memory for locations (Bowler et al., 2014; 2004; Cooper et al., 2015; Semino et al., in preparation), colours (Massand & Bowler, 2015), or the temporal order of item presentation (Bennetto et al., 1996; Bigham et al., 2010; Bowler et al., 2016; Ni Chuileann & Quigley, 2013; Gaigg et al., 2014; Poirier et al., 2011; see Section 1.4.1.4), difficulties in ASD memory are particularly apparent. This is important because relational memory tasks represent the complex nature of situations in daily life better and, therefore, present a more realistic test of everyday functioning.

Another characteristic of ASD memory is a difficulty in explicit memory along with intact implicit memory. As mentioned in Section 1.3.2, *explicit* memory saves information that can be retrieved actively/consciously (Tulving, 2002), and it is typically tested with direct memory tests that ask participants to answer a question about the study episode (e.g., "Have you seen this item previously?"). By contrast, *implicit* memory refers to information that underlies behaviour, but that is not necessarily available for deliberate retrieval (Tulving, 2002). It is tested with indirect tests (e.g., word stem completion tasks, where participants are asked to complete the item with the first thing that comes to mind). An overview of the four previous studies that systematically compared explicit and implicit memory in ASD is presented in Table 3.1. The studies will be described briefly in what follows.

Table 3.1

Overview of studies directly comparing explicit and implicit memory in ASD and TD individuals.

Participant characteristics		Materials		Results		Cohen's
ASD	**TD**			**ASD**	**TD**	*d*
M (SD)	*M (SD)*			*M (SD)*	*M (SD)*	
Bowler, Matthews & Gardiner (1997)						
N 16 (10 m)	16 (8 m)	two word lists, same/different categories				
age 31.20 (11.0)	33.30 (11.4)	Free recall - nr words recalled	unrelated	5.06 (2.18)	5.56 (1.37)	0.27
VIQ[a] 99 (16.7)	96 (13.2)		related	6.13 (1.98)	8.06 (1.06)	1.22
PIQ[b] 86 (19.2)	96 (10.3)	80 words (40 studied), generate vs. read				
		Word stem completion[c]				
		Cued recall test - word stems as cues[c]				
Gardiner, Bowler & Grice (2003) - Exp. 1						
N 16 (13 m)	14 (13 m)	80 words (40 studied), generate vs. read				
age 31.60 (8.9)	31.30 (7.1)	Word fragment completion	Hits-FAs	0.25 (0.19)	0.23 (0.14)	0.15
VIQ[a] 90 (16.8)	93 (13.4)	Cued recall test - word fragments as cues	Hits-FAs	0.35 (0.25)	0.41 (0.21)	0.25
PIQ[b] 86 (18.0)	86 (11.0)					
Gardiner, Bowler & Grice (2003) - Exp. 2						
N 10 (10 m)	10 (10 m)	Word pairs, readability vs. relatedness				
age 28.30 (5.3)	29.10 (4.6)	Cue completion	Hits-FAs	0.15 (0.12)	0.09 (0.12)	0.44
VIQ[a] 96 (17.4)	945 (12.9)	Cued recall test - first word as cue	Hits-FAs	0.23 (0.14)	0.33 (0.20)	0.57
PIQ[b] 85 (13.6)	88 (17.1)					

Participant characteristics			Materials		Results		Cohen's
	ASD	TD			ASD	TD	d
	M (SD)	M (SD)			M (SD)	M (SD)	
Renner, Klinger & Klinger (2000)							
N	14 (11 m)	14 (8 m)	126 black & white images, image naming				
age	10.17 (2.3)	9.33 (2.0)	42 images presented at threshold - image identification	% old vs. new	0.59 (0.30)	0.60 (0.20)	0.04
VIQ[a]	101 (10.8)	109 (7.2)	42 images presented individually -	Hits-FAs	0.95 (0.07)	0.94 (0.07)	0.14
PIQ[b]	98 (12.7)	111 (10.3)	Yes/No recognition test				
			Free recall test	% recalled	0.22 (0.10)	0.23 (0.11)	0.10

Note. [a]Verbal IQ (WAIS or K-BIT). [b]Performance IQ (WAIS or K-BIT). [c]The results were presented only in a graph in Bowler et al. (1997).

Bowler et al. (1997) reported intact cued recall (explicit memory) and word stem completion performance (implicit memory) in ASD, but they found lower free recall (explicit memory) for related word lists in ASD compared to TD adults. In two experiments, using the same materials as Bowler et al. (1997), Gardiner et al. (2003), similarly, found no significant differences between groups on completing word fragments or associated word pairs (implicit memory). However, ASD adults made significantly more FAs on cued recall tests (explicit memory). Increased FA rates may have partly been related to the use of a verbal filler task between study and test phases, which may have confused ASD participants about the study materials. Other between-group differences, however, may have been masked by a lack of statistical power because of the small samples that had been tested, especially in Gardiner et al.'s Experiment 2 (see effect sizes in Table 3.1). Renner et al. (2000) found no significant differences between TD and ASD children on tests of perceptual identification (implicit memory), recognition, or free recall (explicit memory) of black and white line drawings. The interpretation of these results was aggravated by ceiling and floor effects in the recognition and free recall tests, respectively, in both groups. Group differences were, however, obvious when inspecting serial recall curves with primacy and recency effects (higher recall for the beginning and the end items of the list), where ASD children recalled most items from the end of the list, indicating a lack of a primacy effect. Overall, these four behavioural studies suggest intact implicit memory for single words and pictures in children and adults with ASD, but slight difficulties in explicit memory apparent through higher FAs in cued recall tasks, impairments in free recall tasks, and an absence of the typical serial position curve in ASD. Critical is that the tests for explicit and implicit memory neither had the same instructions, nor were they comparable in their processing requirements, i.e., complexity,

which makes it possible that ASD participants may have shown intact implicit memory because the tasks used to measure it were less complex.

To bridge the two distinctions of item/relational and implicit/explicit memory, a paradigm has been developed that was based on the *Process Dissociation Procedure* (PDP; Jacoby, 1991; Jacoby, 1998), measuring explicit and implicit relational memory. In the task, participants were asked to study locations for pictures of objects in pictures of rooms, and they were later either asked to replace the object in its previously studied location ('include' trials), or to pick a new location out of a choice of three, including the objects' old location ('exclude' trials). This task has previously been used in TD OA, who showed a distinction between impaired explicit and intact implicit object-location memory compared to younger TD participants. Based on the ageing analogy of ASD memory (Bowler, 2007) suggesting that memory in (younger) ASD individuals parallels that of TD OA, the use of this paradigm would suggest a similar distinction of intact implicit and impaired explicit relational memory in ASD. According to Postma, Kessels and van Asselen (2008b) object-location memory comprises at least three different processes: the processing of the object, its location, and the binding between object and location. To test the whole object-location memory framework in order to assess where difficulties lie exactly, object and location recognition and an object-location binding task would be needed.

Regarding the two distinctions of item/relational and explicit/implicit memory, Cohen et al. (1997) argued that the distinction between explicit and implicit memory is not very useful. Based on their research on amnesia they argued, that such a distinction does not describe all difficulties in memory that amnesics show, and it also does not explain why they show specific difficulties such as no new vocabulary learning, even when tested with implicit memory tests. These authors favoured the distinction between direct and indirect memory

tests and suggested considering eye-movement measures as indirect tests of memory. That is because eye-movement measures are of potential use to exclude the influence of expectations on memory, for example, older adults' expectations to perform badly on a memory task, will adversely influence their performance. The use of eye-movement measures may enable a comparison between different age groups to investigate the development of memory across time. Eye-movement measures may also allow researchers to develop paradigms for the use with different species (e.g., rodents, humans, nonhuman primates), or different populations (e.g., individuals with disorders, such as amnesia, schizophrenia, and ASD, including less verbal individuals, such as infants or ID populations). The comparison of different species may help to find out more about underlying brain mechanisms of memory, which then may support developing models to better describe memory difficulties in a particular disorder and better try to explain their origin (see Cohen et al., 1997; Hannula et al., 2010; Karatekin, 2007). Finally, Cohen et al. (1997) argued that it may be possible to answer questions measuring eye movements that may not be answered with other measures. As an example, these authors referred to research investigating whether amnesia is a deficit restricted to conscious recollection, in which case amnesics should perform well on indirect tests of memory, including eye-movement measures, or whether the deficit lies in the formation of arbitrary relations between items, in which case indirect measures should also show a deficit. The latter turned out to be the case. Neither reaction times, nor eye movements distinguished between old unchanged and old manipulated scenes, leaving the researchers to conclude that the deficit in amnesia lies in relational memory (Cohen et al., 1997; Ryan, Althoff, Whitlow & Cohen, 2000). Similar results have later been found for schizophrenia (e.g., L. E. Williams et al., 2010), and a similar argument will be made here for ASD.

Memory is reflected in eye movements in various ways. Memory for previously viewed material was shown through very similar patterns of fixations during encoding and retrieval (e.g., Underwood, Foulsham & Humphrey, 2009). In addition, semantic knowledge was found to influence the viewing of images in which objects were either congruent or incongruent with the general context of the image (e.g., Hollingworth, 2009). At retrieval, it has been found that previous viewing of an image ultimately changed the way in which participants viewed it the second time (Ryan, Hannula & Cohen, 2007), a phenomenon researchers called the *eye-movement-based memory effect* (Althoff & Cohen, 1999). Previously studied images in a scene were fixated earlier (R. E. Parker, 1978) and for longer at test as opposed to new images (Ryan et al., 2007), and a comparison with trials that only included unstudied images showed that this effect was because of memory rather than caused by instruction and an intention to select a certain image. Finally, relational memory for locations (e.g., Ryan et al., 2000), pairs of items (e.g., Hannula & Ranganath, 2009), and temporal order (e.g., Ryan & Villate, 2009) has been demonstrated by a *relational manipulation effect*. Regarding location memory, comparisons of eye movements on previously presented scene images with and without detail changes revealed more fixations on manipulated areas in scene images (e.g., Ryan et al., 2000). Most importantly, these effects were evident long before an explicit response was given by participants (Hannula et al., 2007), when no explicit response was requested at all (Hannula et al., 2007), when participants did not distinguish correctly between old and new materials in an explicit test (Cohen et al., 1997), or even when participants were unaware of the relational information their eyes were drawn to (Ryan et al., 2000). Interestingly, in clinical populations that typically show a deficit in explicit relational memory (e.g., amnesia or schizophrenia), this relational manipulation effect has repeatedly been demonstrated to be absent (Hannula et al.,

2007; Ryan et al., 2000; L. E. Williams et al., 2010), indicating a more general difficulty with relational processing beyond explicit memory. Finally, Hannula and Ranganath (2009) reported that the expression of memory in eye movements was, similarly to explicit EM retrieval, related to activity in the hippocampus and PFC, validating the use of eye movements as a measure of memory.

Previous research using eye-movement measurements in ASD is scarce and can mostly be divided up into two strands. The first strand measures eye movements to investigate the underlying neurophysiology that may be different in ASD (Karatekin, 2007 provided an overview of relevant studies). Difficulties in disengaging (Landry & Bryson, 2004) as well as in engaging (Van der Geest, Kemner, Camfferman, Verbaten & van Engeland, 2001) attention have been found through a higher frequency of fast eye movements in ASD as well as both longer (Landry & Bryson, 2004) and shorter (Van der Geest et al., 2001) time needed to look at a stimulus, participants were instructed to look at, suggesting the involvement of the parietal lobes as an underlying neural substrate for eye-movement differences in ASD (Goldberg et al., 2002; Minshew, Luna & Sweeney, 1999; see Sections 1.2.7, 1.4.2.5.2 for details on attention theories in ASD).

The second strand of research is the investigation of eye movements with social stimuli to specify further the social impairments characteristic for ASD (Giuliani & Schenk, 2015). Here, ASD participants have repeatedly been found to fixate for shorter on the eye region of a face in a static image (Dalton et al., 2005; Yi et al., 2014) or a video clip (Klin, Jones, Schultz, Volkmar & Cohen, 2002), and sometimes to fixate for longer on other facial regions, such as the mouth (Klin et al., 2002), or the nose (Yi et al., 2014), indicating a bias in the processing of images. Despite similar total fixation duration on the image as a whole (Hedley, Young & Brewer, 2012), differences in eye-movement patterns at encoding (Snow

et al., 2011) have been found to be related to ASD participants' difficulties in recognising faces (Chawarska & Shic, 2009; Hedley et al., 2012; Snow et al., 2011). Similarly, at retrieval, fixation durations distinguished reliably between previously studied and unstudied images of faces only for TD individuals, again indicating difficulties in recognising previously studied faces in ASD (Hedley et al., 2012).

Other materials than faces have so far only once been utilised to test attention in the context of memory in ASD using eye movements. Loth, Gómez and Happé (2011) asked participants to read stories and then to look at scenes with objects that were relevant, irrelevant, or neutral in the context of the stories. When tested for their memory for objects seen in the pictures, ASD participants recalled fewer story-relevant objects than TD participants and eye-movement data pointed to reduced attention to story-relevant information in ASD during the initial period of scene viewing, suggesting that differences in the allocation of attention during encoding play a role in subsequent retrieval difficulties.

Following the literature reviewed above, the aims of the current study were the following. First, to bridge the distinctions between item/relational and implicit/explicit memory and to follow up on critical points regarding previous literature, it was aimed to systematically compare implicit and explicit relational memory within the same paradigm relying on the same relational processing requirements. Second, to examine the whole object-location memory framework, it was aimed to test memory for objects and locations, in addition to testing memory for object-locations, to see whether difficulties in item memory exist and contribute to relational memory difficulties. Third, the potential effects of age on explicit and implicit relational memory in both groups were of interest. Following previous results on the differences in attention allocation at encoding, it was aimed to assess fixations on the scenes presented at encoding to test for potential between-group differences. To assess

whether results on explicit and implicit relational memory can be replicated and extended with a second less verbal/unconscious measure, fixations at retrieval were examined.

Based on these aims, an object-location memory task based on the PDP (Jacoby, 1991, 1998) was used asking participants to study pictures of objects in locations in pictures of rooms on the computer screen. At test, participants were asked to replace the object in its studied location for the include condition or to choose a new location out of a choice of three locations in the exclude condition. Using the proportion of times participants chose the previously studied location for both, include and exclude, conditions, indices for explicit and implicit memory were calculated with the Jacoby formulae (Jacoby, 1991, 1998). In addition, participants were tested for their memory for the items, i.e., single objects or locations, using Yes/No and source memory tests, asking participants whether they remembered having studied an object or a location and to name locations for the studied objects and objects for the studied locations. Fixations on the object, the scene, and the location were measured at encoding. At retrieval, fixations on the previously studied and new locations were assessed.

First, proportions of target relocations, i.e., proportions of times participants chose the old/studied location for the include and the exclude condition were examined. If ASD participants have difficulties in relational memory, they will show lower target relocations for the include and higher target relocations for the exclude condition compared to TD participants. Second, to analyse these results in more detail, estimates of explicit and implicit relational memory for object-locations were analysed. If ASD participants show particular difficulties in explicit memory, they will show a reduced explicit memory score but a similar implicit memory score compared to TD individuals. Following the second aim to assess item memory in both groups, corrected recognition rates and source scores for objects and locations were examined. If ASD participants have intact item memory, there will be no

between-group differences in object and location memory. If persons with ASD benefit from task support, no between-group differences will be found for source scores of object and location memory tests. Regarding the third aim, if ASD participants' memory is similarly affected by age as TD participants' memory, both groups will show a similar difference in explicit relational memory related to age but no age-difference in implicit memory. Following Aim 4, fixation durations on the scene, the object, and the location presented at encoding were assessed. If ASD individuals show difficulties with relational processing, these will be apparent already at encoding in reduced fixations on the scene image compared to TD participants. Regarding the final aim, fixation durations on the locations presented at retrieval were examined. If persons with ASD show difficulties with relational processing, they will show a reduced eye-movement-based memory effect in reduced fixation durations on previously studied locations compared to TD participants. Therefore, relational memory difficulties will also be present for implicit memory, demonstrating particular difficulties in relational memory rather than explicit retrieval in ASD. Finally, if fixation durations at retrieval reflect a real memory phenomenon, eye-movement data will correlate with behavioural memory data.

3.1.1.2 Predictions

It was expected that ASD adults would show a similar distinction between impaired explicit and intact implicit memory for object-locations as that found in TD OA (see Kessels et al., 2005b). This would be related to lower proportions of target relocations for the include and higher for the exclude condition compared to TD individuals. Item memory and source scores for single objects and locations were expected to be intact in ASD.

Based on Kessels et al. (2005b), no effect of age on implicit relational memory was expected. Based on Experiment 1, it was expected that age would have a more pronounced effect on explicit relational memory in TD as opposed to ASD participants (*safeguard hypothesis* - Geurts & Vissers, 2012; Lever & Geurts, 2016).

Regarding the eye-movement data, based on the literature on face (reviewed in Section 3.1.1.1) and object processing (Loth et al., 2011), reduced attention to the scene image presented at encoding was expected. At retrieval, ASD individuals were expected to show a reduction of the eye-movement-based memory effect found in TD participants (Althoff & Cohen, 1999; Ryan, et al., 2007) with reduced fixation durations on previously studied locations. Therefore, relational memory difficulties would also be present for implicit memory (as demonstrated in Cohen et al., 1997; Ryan et al., 2000; L. E. Williams et al., 2010 for patient populations).

3.1.2 Methods

3.1.2.1 Participants

3.1.2.1.1 Behavioural data

Previous studies of this kind, which have all detected a between-group difference in explicit but not implicit relational memory (Hampstead, Stringer, Stilla, Amaraneni & Sathian, 2011; Kessels, Feijen & Postma, 2005a; Kessels et al., 2005b; Postma, Antonides, Wester & Kessels, 2008a), have included 25 participants per group on average. In addition, power calculation using G*Power (Faul et al., 2007) showed that 16 participants in each group would be needed to find the predicted between-group difference in explicit relational memory with an effect size of Cohen's $d = 1.19$ and a power of 0.90 (Kessels et al., 2005a; R. P. C. Kessels - personal communication, September 2, 2016). After the exclusion of three TD

participants (two men, M_{age} = 54.72 years, age range: 51-62, M_{VIQ} = 100, M_{PIQ} = 99, M_{FIQ} = 100), who did not differ significantly from the rest of the sample in terms of gender, X^2 = 0.07, p = .79, CA, VIQ, PIQ, or FIQ, t_{max} < 1.73, p_{min} > .09, Cohen's d_{max} < 1.07, 95 % CI_{max}(-0.21, 2.26), and whose testing sessions had either been disrupted by loud building noise, who had reported getting confused by the task instructions, or who had performed the task at chance level, the final sample included 23 TD (17 men, M_{age} = 40.87 years, age range: 20-61) and 25 ASD adults (20 men, M_{age} = 42.13 years, age range: 25-69), all performing above chance on the task. Groups were closely matched on gender, X^2 = 0.25, p = .62, CA, VIQ, PIQ, and FIQ, as measured by the WAIS-III^{UK} (The Psychological Corporation, 2000; see Table 3.2). ASD compared to TD participants had significantly higher scores on the AQ (Baron-Cohen et al., 2001). Twenty-two ASD individuals were assessed with the ADOS (Lord et al., 1989). Three of these had total scores just below the cut-off score of seven, but they were nevertheless included in the sample since they all had received a formal clinical diagnosis of an ASD before testing. Similarly to Experiment 1, ASD participants reporting comorbidities and psychotropic medication use were included in the sample (see Section 2.1.2.1). In the current study, 28 % of ASD participants had reported comorbidities and/or psychotropic medication use. Dyslexia (29 %), depression (14 %), anxiety disorder (14 %) and ADHD (14 %) were most common. In addition, 57 % of ASD participants took antidepressants, and 14 % took antipsychotic medication. ASD individuals with and without comorbidities and medication use did not differ significantly in terms of gender, X^2 = 0.45, p = .50, CA, VIQ, PIQ, and FIQ, t_{max} < 1.34, p_{min} > .19, Cohen's d_{max} < 0.59, 95 % CI_{max}(-0.31, 1.47). In addition, analysing the data without ASD individuals that reported comorbidities and/or medication use left the results reported below unaffected.

Table 3.2

Descriptive statistics for ASD and TD individuals, who participated in Experiment 2.

| Measure | ASD (20m, 5f) | | TD (17m, 6f) | | | Cohen's | | |
	M	*SD*	*M*	*SD*	*t*(46)	*p*	*d*	CI
Age (years)	42.13	13.2	40.87	13.5	0.33	.75	0.09	-0.47, 0.66
VIQ[a]	108	15.0	114	12.3	1.41	.17	0.41	-0.17, 0.97
PIQ[b]	106	15.6	109	11.0	0.88	.39	0.25	-0.32, 0.82
FIQ[c]	108	15.4	113	12.2	1.23	.22	0.36	-0.22, 0.92
AQ[d]	32.58	6.2	14.13	5.8	10.59[e]	.00	3.09	2.20, 3.88
ADOS-C[f]	2.68 (0-6)	1.5						
ADOS-RSI[g]	6.27 (3-12)	2.5						
ADOS-Total[h]	8.95 (5-17)	3.1						
ADOS-Im[i]	1.24 (0-2)	0.6						
ADOS-SB[j]	1.27 (0-3)	1.1						

Note. [a]Verbal IQ (WAIS-III[UK]). [b]Performance IQ (WAIS-III[UK]) [c]Full-scale IQ (WAIS-III[UK]). [d]AQ - Autism-Spectrum Quotient. [e]here *t*(45) - all participants, but one ASD individual, had filled in the AQ. [f]ADOS - Communication subscale. [g]ADOS - Reciprocal Social Interaction subscale. [h]ADOS Total score - Communication + Reciprocal Social Interaction. [i]ADOS - Imagination/Creativity subscale. [j]ADOS - Stereotyped Behaviours and Restricted Interests subscale. For ADOS scores, range of scores in brackets.

No implicit memory score was available for six TD (four men, $M_{age} = 35.54$ years, age range: 20-53, $M_{VIQ} = 120$, $M_{PIQ} = 112$, $M_{FIQ} = 118$) and four ASD individuals (three men, $M_{age} = 38.60$ years, age range: 32-50, $M_{VIQ} = 117$, $M_{PIQ} = 118$, $M_{FIQ} = 120$), who performed at ceiling. They did not differ significantly from the rest of the sample in terms of gender, X^2_{max}

= 0.22, p_{min} = .64, and CA, t_{max} < 1.14, p_{min} > .26, Cohen's d_{max} < 0.55, 95 % CI_{max}(-0.42, 1.46). However, whereas the excluded TD adults had similar VIQs, PIQs, and FIQs, t_{max} < 1.40, p_{min} > .17, Cohen's d_{max} < 0.67, 95 % CI_{max}(-0.31, 1.59), as the rest of the TD sample, the excluded ASD adults had significantly higher VIQs, t_{VIQ} = 2.60, p_{VIQ} = .02, Cohen's d_{VIQ} = 0.72, 95 % CI_{max}(-0.39, 1.78), and slightly higher PIQs, t_{PIQ} = 1.81, p_{PIQ} = .08, Cohen's d_{PIQ} = 0.99, 95 % CI_{max}(-0.15, 2.06), and FIQs, t_{FIQ} = 1.76, p_{FIQ} = .09, Cohen's d_{FIQ} = 0.96, 95 % CI_{max}(-0.17, 2.03), compared to the other ASD participants. The remaining 17 TD (13 men, M_{age} = 42.76 years, age range: 23-61) and 21 ASD (17 men, M_{age} = 42.80 years, age range: 25-69) participants were still matched in terms of gender, X^2 = 0.11, p = .74, CA, VIQ, PIQ, and FIQ, t_{max} < 1.18, p_{min} > .24, Cohen's d_{max} < 0.39, 95 % CI_{max}(-0.27, 1.02).

3.1.2.1.2 Eye-movement data

Four (two men, M_{age} = 40.58 years, age range: 23-58, M_{VIQ} = 114, M_{PIQ} = 111, M_{FIQ} = 114) out of 23 TD and five (four men, M_{age} = 46.81 years, age range: 31-62, M_{VIQ} = 114, M_{PIQ} = 101, M_{FIQ} = 109) out of 25 ASD individuals, who did not differ significantly from the rest of the sample in terms of gender, X^2_{max} = 1.44, p_{min} = .23, CA, VIQ, PIQ, or FIQ, t_{max} < 0.92, p_{min} > .37, Cohen's d_{max} < 0.46, 95 % CI_{max}(-0.55, 1.43), were excluded from the analyses because customised Matlab routines had indicated that more than 20 % of their eye-movement data were invalid, leaving a sample of 19 TD (15 men, M_{age} = 40.94 years, age range: 20-61) and 20 ASD adults (16 men, M_{age} = 40.96 years, age range: 25-69). Groups were matched on gender, X^2 = 0.01, p = .94, CA, VIQ, PIQ, and FIQ (see Table 3.3).

Table 3.3

Descriptive statistics for ASD and TD participants for whom eye-movement data were available in Experiment 2.

| Measure | ASD (16m, 4f) | | TD (15m, 4f) | | | | Cohen's | |
	M	*SD*	*M*	*SD*	*t*(37)	*p*	*d*	CI
Age (years)	40.96	13.1	40.94	13.0	0.01	1	0.00	-0.63, 0.63
VIQ[a]	107	16.1	114	11.4	1.54	.13	0.49	-0.15, 1.12
PIQ[b]	107	16.5	109	10.3	0.43	.67	0.14	-0.49, 0.76
FIQ[c]	107	16.6	112	11.1	1.09	.28	0.35	-0.29, 0.98
AQ[d]	32.68	5.4	15.21	5.4	10.02[e]	.00	3.25	2.23, 4.14
ADOS-C[f]	2.11 (0-4)	1.2						
ADOS-RSI[g]	5.61 (3-10)	2.0						
ADOS-Total[h]	7.72 (3-12)	2.0						
ADOS-Im[i]	1.24 (0-2)	0.7						
ADOS-SB[j]	1.00 (0-3)	1.0						

Note. [a]Verbal IQ (WAIS-III[UK]). [b]Performance IQ (WAIS-III[UK]) [c]Full-scale IQ (WAIS-III[UK]). [d]AQ - Autism-Spectrum Quotient. [e]here *t*(36) - all participants, but one ASD individual, had filled in the AQ. [f]ADOS - Communication subscale. [g]ADOS - Reciprocal Social Interaction subscale. [h]ADOS Total score - Communication + Reciprocal Social Interaction. [i]ADOS - Imagination/Creativity subscale. [j]ADOS - Stereotyped Behaviours and Restricted Interests subscale. For ADOS scores, range of scores in brackets.

Eye-movement data were further investigated by splitting them up by later accuracy in the behavioural test. Six TD (four men, M_{age} = 35.54 years, age range: 20-53, M_{VIQ} = 120, M_{PIQ} = 112, M_{FIQ} = 118) and three ASD individuals (all men, M_{age} = 34.91 years, age range: 32-40,

$M_{\text{VIQ}} = 116$, $M_{\text{PIQ}} = 122$, $M_{\text{FIQ}} = 121$), who did not differ significantly from the rest of the sample in terms of gender, $X^2_{\text{max}} = 0.88$, $p_{min} = .35$, CA, VIQ, PIQ, or FIQ, $t_{\text{max}} < 1.79$, $p_{\text{min}} > .09$, Cohen's $d_{\text{max}} < 1.13$, 95 % $\text{CI}_{\text{max}}(-0.20, 2.34)$, did not make mistakes in the behavioural test and, therefore, had to be excluded from the analysis for incorrect trials, leaving a sample of 13 TD (11 men, $M_{\text{age}} = 43.43$ years, age range: 26-61) and 17 ASD (13 men, $M_{\text{age}} = 42.03$ years, age range: 25-69) individuals. Groups were still matched on gender, $X^2 = 0.31$, $p = .58$, CA, VIQ, PIQ, and FIQ, $t_{\text{max}} < 1.17$, $p_{\text{min}} > .25$, Cohen's $d_{\text{max}} < 0.42$, 95 % $\text{CI}_{\text{max}}(-0.34, 1.12)$.

3.1.2.2 Materials

3.1.2.2.1 Object-location task

To choose object locations for the main study, 22 (six men) City, University of London undergraduate students, aged 19 to 40 years ($M_{\text{age}} = 24.37$), took part in a pilot study. Nine to 12 context-appropriate pictures of objects (e.g., a toothbrush in the bathroom), each, were presented with seven pictures of rooms (e.g., kitchen, bathroom) on a computer screen. Pictures of the rooms filled approximately 80 % of the screen, and objects were presented, one at a time, underneath the room pictures. Participants were asked to click on up to 15 different locations that they considered appropriate for each object (e.g., a toothbrush was put next to the sink, in the cabinet above the sink, or next to the bath, etc., in the bathroom). All selected locations of all participants were then superimposed on the room pictures and a 96-cell grid overlay was used to rank-order all possible object locations in terms of the frequency with which participants had endorsed them as plausible. Three locations were then selected for each object for the experiment proper – a target location, in which the object was to be presented during the learning trials, and two distracter locations for the test trials. The target location was always the location in the middle of the rank order distribution of the pilot study, while avoiding the same location for targets of different objects. One distracter

location was chosen to be ranked as more likely (but not the most likely) and the other as less likely (but not the least likely) than the target location. Objects with an insufficient number of plausible locations were excluded. Finally, adjustments were made to render all locations appropriate (e.g., a watering can was put on top of a table in the picture of the garden, instead of half way on top and half way underneath it). One room with five objects for practice trials and six rooms with eight objects each for experimental trials were selected. An overview of all rooms with their objects is provided in Table A2 in Appendix 2.

3.1.2.2.2   Object and Location recognition and source memory

In addition to the 48 objects from the object-location task, 48 new objects were presented as foil items in the *object recognition* test, making 96 coloured pictures of everyday items.

In addition to the 72 target and distracter locations for the 24 objects that participants had studied during the object-location test, 24 new locations were presented as foils in the *location recognition* test, making 96 locations in total. These 96 locations were formed by 16 locations for each of the seven rooms. Out of the 16 locations, 12 were familiar from the object-location task, i.e., four target (one for each object) and eight distracter locations (two for each object), and four were new locations (one for each object) that were chosen to be more or less likely than the target and distracter locations.

3.1.2.3   Procedure

3.1.2.3.1   Object-location task

Standard measures of memory are often criticised, because of their tendency to overestimate recollection in not taking into account automatic processes or guessing (Jacoby, Toth & Yonelinas, 1993). An alternative, the PDP, was developed by Jacoby (1991, 1998) that aimed at increasing recollection accuracy by setting recollection in relation to "informed guessing"

(so-called more automatic processes, which Yonelinas, 2002 referred to as familiarity). To do this, Jacoby et al. (1993) used *exclude* and *include* instructions and developed formulae to directly calculate the contribution of recollection and familiarity to memory performance. Under the *include* instruction, participants are asked to respond with the material they studied previously (e.g., an originally studied location for an object). A correct response is either the result of recollection (Rec in the formulae) or familiarity (F in the formulae) in case recollection fails.

$$\text{Include} = \text{Rec} + \text{F} * (1 - \text{Rec}) \tag{1}$$

In the *exclude* condition, participants are instructed to complete the question with a new unstudied answer (e.g., a new location for the studied object). Participants are expected to answer with the old material (e.g., the objects' old studied location), if conscious recollection fails and more automatic processes take over.

$$\text{Exclude} = \text{F} * (1 - \text{Rec}) \tag{2}$$

Recollection results from the difference between the proportions of old material in include and exclude conditions.

$$\text{Rec} = \text{Include} - \text{Exclude} \tag{3}$$

Familiarity is the quotient of exclude and failed recollection.

$$\text{F} = \text{Exclude} / (1 - \text{Rec}) \tag{4}$$

The procedure assumes that recollection and familiarity are independent, which is in line with most other models of recognition memory (Yonelinas, 2002). Recollection has been argued to occur in include and exclude conditions with equal probability, especially when the order of the presentation of the conditions is mixed (Jacoby et al., 1993). The influence of familiarity is thought to be constant in both conditions, which can be checked, empirically, by calculating FA rates (i.e., a participant indicates a new item as old). If these are similar in

both conditions, the influence of familiarity is thought to be equal. For differing levels of FAs for recollection and familiarity, procedures of correction have been developed (Roediger & McDermott, 1994). In contrast to the R/K procedure, the PDP is a more strict measure of recollection in that participants are told what to remember. If they remember something else about the material from the study phase (e.g., the thoughts they had at the time of encoding), this partial recollection is not measured with the procedure (Yonelinas, 2002). Because the original procedure (Jacoby, 1991) does not take correct guesses into account (Buchner, Erdfelder & Vaterrodt-Plunnecke, 1995), Buchner et al. (1995) and Caldwell and Masson (2001) developed means to control for them. The PDP has been used widely to measure explicit and implicit memory (e.g., David & Brown, 2003; Destrebecqz et al., 2005; Postma et al., 2008b; Hampstead et al., 2011), since there are studies suggesting a relation between conceptual implicit memory and familiarity (Wagner, Gabrieli & Verfaellie, 1997; W. C. Wang, Ranganath & Yonelinas, 2014; W. C. Wang & Yonelinas, 2012).

In the current study, the paradigm required participants to recall the locations of objects, by placing them into the previously studied locations (include trials) or in new locations (exclude trials). This procedure allowed the calculation of estimates of explicit and implicit memory (see formulae presented above).

The task was presented on a computer screen using E-Prime software. Following a familiarisation phase of five practice trials, participants were presented with 24 *study* trials in which they were asked to memorise the locations for four object pictures each in six pictures of rooms. In each trial, participants were shown a picture of a room with a red frame, highlighting a target location in the room, and an object picture presented underneath the room image, on the computer screen. Participants were asked to click on the object image (object-click; Phase 1), after which a red frame appeared around it. Next they needed to click

on the location (location-click; Phase 2), after which the object image was presented in this location for 3 s before the next trial started (object in location; Phase 3; see Figure 3.1).
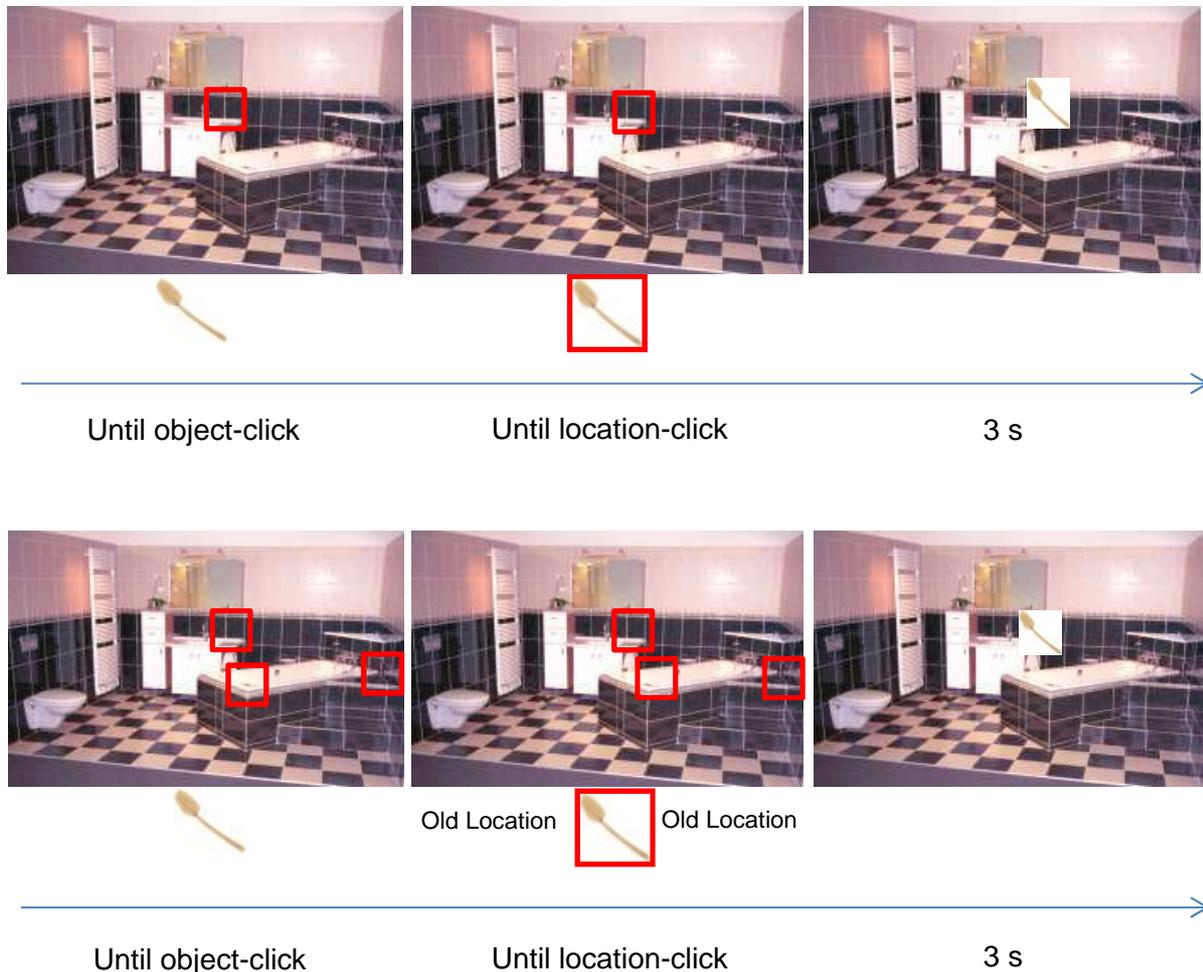
Figure 3.1. Examples of study phase (top) and test phase (bottom).

At *test*, which followed right after study, participants were assessed for their memory for the object locations in the rooms. The 24 originally studied objects were intermixed with 24 new objects (four per room) to control for chance performance. This time, three locations were highlighted by red frames in the room images, and participants were instructed, first, to click on the object (object-click; Phase 1), after which a red frame appeared around it, and the instructions – old location or new location – appeared on both sides of the object image.

According to the instructions, participants had to select one of the three locations by clicking on it (location-click; Phase 2), i.e., the previously studied location for old location (the include condition) or one of the two new locations for new location (the exclude condition), after which the object image appeared in the selected location for 3 s (object in location; Phase 3; see Figure 3.1), and the next trial started. Importantly, the instructions placed very similar demands on the participants in terms of retrieval effort.

At study and test, participants were asked to comment on the task by naming the objects, by reading out loud the instructions, and by describing the selected locations briefly, to ensure that they were paying full attention, and that they verbalised the materials to a similar extent. Objects were counterbalanced across the test conditions, i.e., across participants each object was tested under include and exclude conditions an equal number of times. The two sets of 24 items were counterbalanced across participants, so that half of the participants studied items from Set A and saw items from Set B as new items and vice versa for the other half of the participants. The order of trial presentation and test conditions was completely randomised.

3.1.2.3.2   Object and Location recognition and source memory tests

Participants' memory for objects and locations presented in the object-location task was tested in separate recognition memory tasks, intermixing previously presented items with new materials to control for chance performance.

In the *object recognition* task, participants were presented with 96 pictures of objects, one at a time on the computer screen, and were asked to indicate whether they had seen an object previously in the object-location task, using a Yes/No procedure. For objects identified as familiar from the previous task, participants were asked to name one of the objects'

locations from the object-location task verbally to test source memory. Participants' verbal responses were audio-recorded for further analysis.

Similarly, for the *location recognition* task participants were presented with 96 images of the rooms with one location each highlighted. Participants were asked to indicate if they had seen the exact location highlighted in the object-location task, using a Yes/No procedure. For a Yes answer, participants were asked to name the object they had studied in this location previously. This source information was audio-recorded for further analysis.

Because of a recording problem during one of the testing sessions, audio-recordings were available for all participants but one ASD individual. Audio-recordings were transcribed and scored in that participants received credit for naming the correct objects or locations. Regarding the locations, participants were allowed to choose from the three locations each object was presented with during the object-location task (one target, two distracters). If there was more than one possible location that fitted the participants' description, they were given credit in the benefit of the doubt (e.g., "Some scales, yes I do remember, and I remember putting them in the middle of the floor in the bathroom."). Similarly, in seldom cases, where two objects (one from the study and one from the test set) had been placed in the same location during the task, credit was given for naming either of the two. This was the case for 16 out of the 144 possible locations (48 objects, three locations each). Groups did not differ in the number of times they named an object from the test rather than the study set, $X^2 = 3.52$, $p = .47$ ($N_{ASD} = 31$, $M_{ASD} = 1.29$; $N_{TD} = 26$, $M_{TD} = 1.13$).

3.1.2.3.3 Eye movements

There are different types of eye movements. In contrast to saccades, which are very fast eye movements to a point of interest, fixations are periods of relative pause between saccades, in which the eye takes in information at the sharpest point of vision, the fovea. Fixations are

typically defined as having a minimum duration of 100 ms, and they usually last between 200 - 300 ms (Hannula, Ryan, Tranel & Cohen, 2007). During fixations the eyes are, however, not static, but they show small movements (Martinez-Conde, Macknik & Hubel, 2004). Fixations take longer when a task is more difficult and the longer a task lasts, the more often the eye returns to points of interest, instead of analysing every little detail of an image. The area fixated is taken as a measure of what is attended to, and the duration of a fixation is seen as an indicator of how much time an individual needs to process the information that is attended to (Karatekin, 2007). On this basis, researchers distinguish between eye movements directed at the whole display, for example, an image of a scene, and eye movements related to specific regions of interest (ROI), defined by the experimenter, such as eye and mouth regions in a face (Hannula et al., 2010), or objects and locations for these objects in the scene image. The data is typically presented as a proportion of viewing time by dividing the time spent looking on a ROI either by the total time spent looking on the stimulus, or by the total trial duration (Hannula et al., 2010).

In the current study, eye movements were monitored throughout the object-location memory task (but not the item tests) using a Tobii TX300 eye-tracker with a sampling rate of 120 Hz. The measurement started after a standard five-point calibration procedure. After data collection, customised Matlab routines extracted the durations, latencies, and co-ordinates of all fixations lasting a minimum of 100 ms. Regarding *encoding*, total fixation durations were averaged across all trials to derive the average length of time participants spent looking at the scene, the object, and the target location. These data were then further split up by behavioural accuracy, deriving average looking times on scene, object, and target location for trials on which participants subsequently gave correct and incorrect responses at test. For *retrieval*, total fixation durations were averaged across trials to derive average looking times for the

target location and an average for the two distracter locations, separately for include and exclude test conditions and the three phases of the trial (i.e., object-click, location-click and viewing of the object in location; see Figure 3.1). The analysis focussed on Phase 2 (location-click) – the period of active retrieval – lasting from the appearance of the instructions on the screen until the selection of the location by the participant. Preliminary analysis showed that most eye movements happened in this period.

3.1.3 Results

Results were analysed using Chi-Squared tests for nominal data, independent samples t-tests, repeated measures ANOVAs and ANCOVAs, bivariate correlations, and linear regression analyses. GGC was applied in case the Sphericity assumption was violated. The significance level was chosen at .05 for all tests and post hoc tests were calculated for significant differences. Cohen's *d* and partial Eta-Squared are reported as effect size measures.

3.1.3.1 Object-location task

3.1.3.1.1 Accuracy

The proportions of times participants chose the previously studied/target locations were calculated for the include condition, where participants had been asked to click on the old location (in this case a correct answer), and for the exclude condition, where they had been asked to click on a new location (clicking on the old location would in this case have been an incorrect answer). Analysing these proportions for the 24 previously unstudied objects and their locations showed that the target and distracter locations had been chosen equally often, independent of instructions in both groups. In addition, these estimates did not differ significantly from .33, which was the expected percentage of chance target relocations for a choice of three different locations for each object (chance include: $M = 0.30$, $SD = 0.12$, $t(47)$

= 1.52, p = .14; chance exclude: M = 0.31, SD = 0.17, $t(47)$ = 0.93, p = .36). Thus, all remaining analyses focussed exclusively on target relocations for the studied objects.

A 2 (Group [ASD, TD]) x 2 (Instruction [Include, Exclude]) repeated measures ANOVA, analysing proportions of target relocations, showed a marginal main effect of *Group*, $F(1,46)$ = 3.61, p = .06, Cohen's d = 0.55, 95 % CI(-0.04, 1.12), with more old location clicks in the TD compared to the ASD group, and a significant main effect of *Instruction*, $F(1,46)$ = 739.43, p < .001, Cohen's d = 6.28, 95 % CI(5.26, 7.19), with a higher number of old locations chosen in the include compared to the exclude condition. There was also a significant *Group x Instruction* interaction, $F(1,46)$ = 4.50, p < .05, η_p^2 = .09, with a higher target relocation rate in the TD (M = 0.89, SD = 0.12) compared to the ASD group (M = 0.79, SD = 0.19) in the include condition, p < .05, Cohen's d = 0.64, 95 % CI(0.05, 1.21), but similar proportions of choosing the old location in the two groups for exclude (M_{TD} = 0.04, SD_{TD} = 0.07; M_{ASD} = 0.06, SD_{ASD} = 0.08), p = .36, Cohen's d = 0.26, 95 % CI(-0.31, 0.83), (see Figure 3.2).
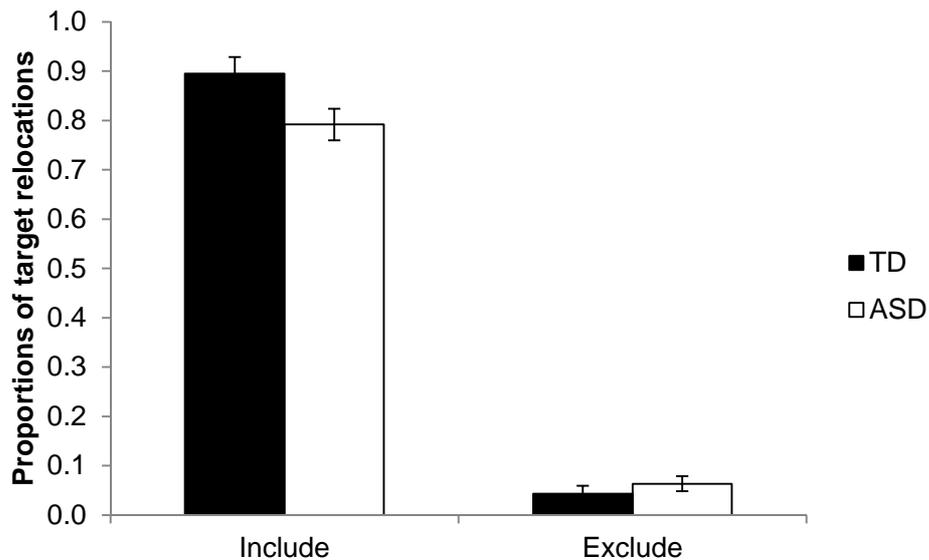
Figure 3.2. Proportions of old location choices (target relocations) for include (old location) and exclude (new location) conditions for ASD and TD groups in Experiment 2. The data are presented as mean ± SEM.

The proportions of target relocations for include and exclude conditions were used to calculate estimates of implicit and explicit memory, using the formulae by Jacoby (1991, 1998). The estimate of *Explicit* memory was determined by the difference between Include (I) and Exclude (E) proportions of target relocations.

$$\text{Explicit Memory} = I - E \tag{5}$$

Implicit memory corresponded to the quotient of Exclude target relocations and the difference between 1 and the estimate of Explicit memory.

$$\text{Implicit Memory} = E/(1 - \text{Explicit Memory}) \tag{6}$$

The data are set out in Figure 3.3. An implicit memory score was available for 17 TD and 21 ASD participants, as six TD and four ASD individuals performed perfectly in both conditions. When comparing the numbers of perfectly performing participants, there were no significant differences between groups in include (no mistakes/mistakes - TD: 8/15, ASD:

7/18; $X^2 = 0.26$, $p = .61$) or exclude conditions (no mistakes/mistakes - TD: 15/8, ASD: 14/11; $X^2 = 0.43$, $p = .51$). The data for explicit and implicit memory were analysed using separate independent samples t-tests, because the two scores had been calculated from the same values (data from inclusion and exclusion trials) and were, therefore, not independent from one another. Whereas TD ($M = 0.85$, $SD = 0.16$) compared to ASD ($M = 0.73$, $SD = 0.23$) individuals showed significantly higher *explicit memory*, $t(43.20) = 2.15$, $p < .05$, Cohen's $d = 0.60$, 95 % CI(0.02, 1.18), no difference between groups was found for *implicit memory* ($M_{TD} = 0.26$, $SD_{TD} = 0.34$; $M_{ASD} = 0.27$, $SD_{ASD} = 0.36$), $t(36) = 0.08$, $p = .94$, Cohen's $d = 0.02$, 95 % CI(-0.62, 0.66), (see Figure 3.3).
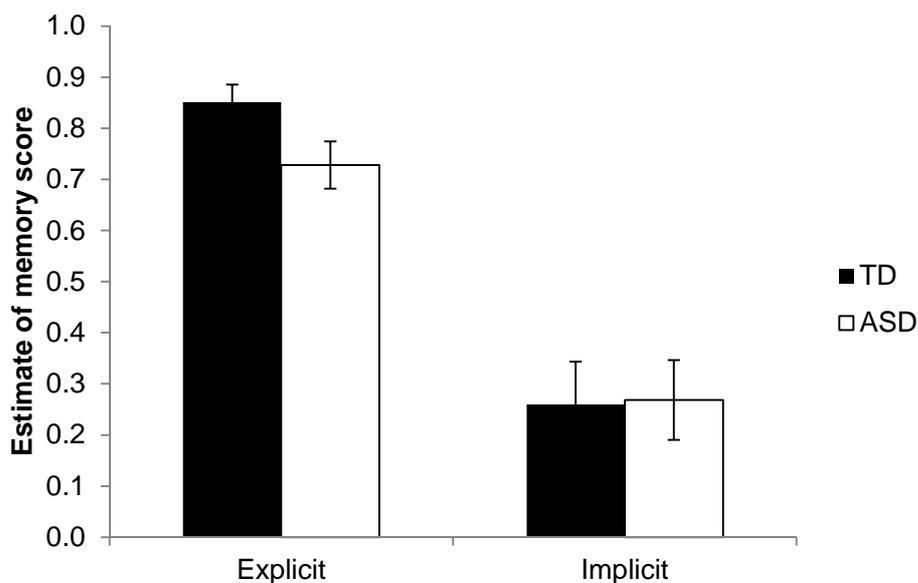
Figure 3.3. Estimates for explicit and implicit memory for Experiment 2, calculated from scores for include and exclude conditions according to Jacoby (1991) formulae, with explicit memory displayed for 23 TD and 25 ASD individuals and implicit memory available for 17 TD and 21 ASD individuals. The data are presented as mean $\pm$ SEM.

To address the criticism that the Jacoby (1991) formulae do not take guess rates into account, the analyses were re-run using the multinomial model (Buchner et al., 1995) to calculate implicit and explicit memory estimates accounting for guesses. The results showed again a clear difference between groups in *explicit*, $t(37.93) = 2.20$, $p < .05$, Cohen's $d = 0.62$, 95 % CI(0.03, 1.19), but not *implicit relational memory*, $t(36) = 0.28$, $p = .78$, Cohen's $d = 0.09$, 95 % CI(-0.55, 0.73).

3.1.3.1.2   Response times

Response times were analysed to ensure that eye-movement data were not confounded by systematic differences between groups in the length of encoding and retrieval phases of the task. Because of the way participants interacted with the materials of the task (i.e., naming and clicking on the object and location images), the duration of study as well as test trials was different for every participant. Table 3.4 presents response times for the two groups for encoding as well as retrieval. The duration of encoding did not differ significantly between groups, $t(37) = 0.88$, $p = .39$, Cohen's $d = 0.28$, 95 % CI(-0.29, 0.84). Similarly, a 2 (Group [ASD, TD]) x 2 (Instruction [Include, Exclude]) repeated measures ANOVA for retrieval response times in Phase 2 showed no significant main effects or interactions, $F_{max} < 2.59$, $p_{min} > .10$, $\eta_{p\ max}^2 < .07$, confirming that response times did not differ significantly between groups or conditions at retrieval.

Table 3.4

Response times in ms for the total duration of encoding and the duration of the second retrieval phase Location-click, split up by conditions for ASD and TD groups in Experiment 2.

	ASD	TD
	M (*SD*)	*M* (*SD*)
Encoding overall	12155.54 (3989.09)	13177.93 (3242.73)
Retrieval Phase 2: Location-click		
Include condition	6982.05 (2443.45)	7658.36 (2797.07)
Exclude condition	6950.89 (2431.95)	8430.45 (2344.24)

3.1.3.1.3   Exploratory regression analyses regarding the effects of age

Finally, because of the well-known effects of advancing age on memory (e.g., Kessels et al., 2005b), and because of the similarity between memory in autism and typical ageing (ageing analogy; Bowler, 2007), the effect of age on explicit and implicit relational memory was investigated, first, by running bivariate correlations. Table 3.5 shows that there were no significant correlations between age and explicit and implicit relational memory.

Table 3.5

Bivariate correlations between explicit and implicit relational memory scores and age for the participants of Experiment 2.

	Explicit	**Implicit**
age	-.19	-.15

Note. * significant at $p < .05$. ** significant at $p \leq .01$.

It was, however, possible that the correlation coefficients were affected by a third variable that may have influenced the relationship between explicit memory and age (Bewick et al., 2003), and this variable may have been group in that age may have had a different effect on memory in the two groups. Therefore, second, multiple linear regression analyses were performed, including Age and a Group x Age interaction term, to predict behavioural memory performance. The Group x Age interaction term explained 14.1 % of the variance, $R^2 = .14$, $F(1,46) = 7.58$, $p = .008$, and it significantly predicted explicit relational memory, $\beta = -.38$, 95 % CI(-0.01, 0.00), $p < .01$. Visual inspection of Figure 3.4 showed that age was a better predictor of explicit memory in the ASD as opposed to the TD group. Neither Age nor a Group x Age interaction term explained any variance in implicit relational memory.
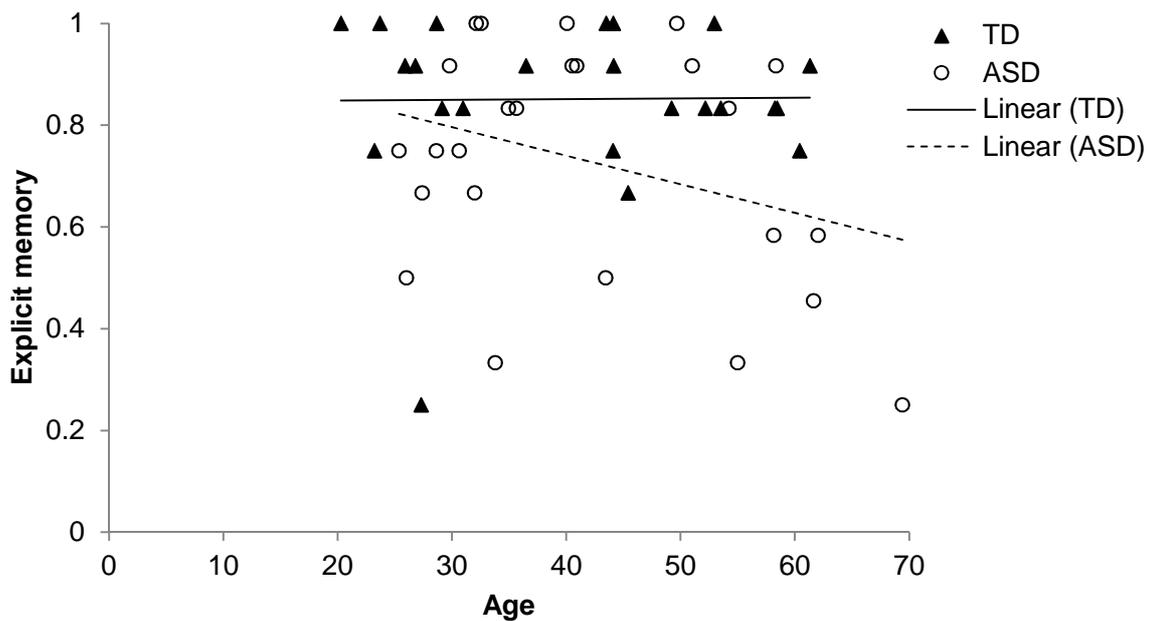
Figure 3.4. The relationship between age and explicit location memory in Experiment 2 with a stronger age-related difference in explicit memory in ASD compared to TD participants.

3.1.3.2 Object and Location recognition and source memory tests

Corrected recognition rates (Hits minus FAs; outlined in Table 3.6) were calculated separately for *objects* participants had interacted with once, i.e., new objects participants saw at test, and objects they had been presented with twice, i.e., target objects participants saw at study and test. The data were analysed using a 2 (Group [ASD, TD]) x 2 (Repetition [1 interaction vs. 2 interactions]) repeated measures ANOVA. A significant main effect of *Repetition*, $F(1,46) = 15.90$, $p < .001$, Cohen's $d = 0.69$, 95 % CI(0.27, 1.09), showed that objects interacted with twice were remembered better than objects interacted with once. There was no other significant main effect or interaction, $F_{max} < 2.49$, $p_{min} > .12$, $\eta_p^2{}_{max} < .05$. Source scores (see Table 3.6) indicated that both groups remembered similar numbers of locations for objects they had recognised from the previous task, $t(38.98) = 0.24$, $p = .81$, Cohen's $d = 0.07$, 95 % CI(-0.50, 0.64).

Corrected recognition rates for *locations* were split up by the number of times a participant clicked on the locations (i.e., number of interactions). The data, outlined in Table 3.6, were analysed using a 2 (Group [ASD, TD]) x 3 (Repetition [no interaction, 1 interaction, 2 interactions] repeated measures ANOVA. A significant main effect of *Repetition*, $F(1.69,76.11) = 186.16$, $p < .001$, $\eta_p^2 = .81$, GGC, showed that locations were remembered better with an increasing number of interactions in the object-location task (0 interactions < 1 interaction < 2 interactions), all $p < .001$, all Cohen's $d > 0.74$, 95 % CI$_{min}$(0.33, 1.16). No other main effect or interactions were significant, $F_{max} < 0.25$, $p_{min} > .61$, $\eta_p^2{}_{max} < .01$. Source score (see Table 3.6) analysis[11] showed that both groups remembered a similar number of objects for locations recognised from the object-location task, $t(45) = 0.30$, $p = .76$, Cohen's $d = 0.09$, 95 % CI(-0.49, 0.66).

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[11] The direction of results for object and location recognition was the same when only the 17 TD and 21 ASD individuals for whom an implicit memory score in the object-location task was available were included.

Finally, to rule out that the large age-range and, therefore, age-related variability in the data may have obscured possible group differences, all analyses were repeated including age as a covariate. The only difference from the findings just presented was in the results for object recognition. An ANCOVA with age showed no significant main effects of Group or Repetition and no Group x Repetition interaction, $F_{max} < 2.35$, $p_{min} > .13$, $\eta_p^2{}_{max} < .05$, for object recognition. However, a significant *Repetition x Age* interaction, $F(1,45) = 7.95$, $p < .01$, $\eta_p^2 = .15$, indicated that the older individuals in the sample were worse at learning objects over repeated presentations. A lack of main effects or interactions with the Group factor suggested that age effects operated similarly in the two groups.

Table 3.6

Corrected recognition rates for object and location recognition tasks, split up by the number of interactions with objects and locations during the object-location memory test, and source memory scores for objects and locations for ASD and TD groups in Experiment 2.

Measure	ASD M (SD)	TD M (SD)
Object recognition (23 TD, 25 ASD)		
1 interaction	0.88 (0.18)	0.94 (0.08)
2 interactions	0.97 (0.05)	0.99 (0.02)
Total object source score (23 TD, 24 ASD)	0.81 (0.13)	0.82 (0.08)
Location recognition (23 TD, 24 ASD)		
no interaction	0.21 (0.11)	0.17 (0.11)
1 interaction	0.50 (0.21)	0.50 (0.19)
2 interactions	0.65 (0.18)	0.63 (0.18)
Total location source score (23 TD, 24 ASD)	0.35 (0.08)	0.35 (0.07)

3.1.3.3 Correlations among behavioural tasks

As can be seen in Table 3.7, significant positive correlations were found among explicit relational memory and object and location recognition, and source scores. There were no significant correlations between implicit memory and any of the other measures.

Table 3.7

Bivariate correlations among explicit and implicit relational memory scores for the object-location task, corrected object and location recognition rates, and object and location source scores from Experiment 2.

	Explicit	Implicit	Object	Location	Object source	Location source
Explicit	1	.04	.59**	.52**	.52**	.49**
Implicit		1	-.06	.12	-.09	-.11
Object			1	.35*	.49**	.21
Location				1	.34*	.68**
Object source					1	.55**
Location source						1

Note. * significant at $p < .05$. ** significant at $p \leq .01$.

3.1.3.4 Eye movements during the object-location task

3.1.3.4.1 Encoding

3.1.3.4.1.1 Overall

The data, presented in Figure 3.5, were analysed using a 2 (Group [ASD, TD]) x 3 (ROI [Object, Scene, Location]) repeated measures ANOVA. This showed a significant main effect of *ROI*, $F(1.72, 63.44) = 80.80$, $p < .0001$, $\eta_p^2 = .69$, GGC, with (marginally) longer average

fixations at the Scene compared to the Location, $p < .0001$, Cohen's $d = 1.46$, 95 % CI(0.95, 1.95), compared to the Object, $p = .05$, Cohen's $d = 0.34$, 95 % CI(-0.11, 0.78). There was no main effect of Group or Group x ROI interaction, $F_{max} < 2.08$, $p_{min} > .13$, $\eta_{p\,max}^2 < .06$.
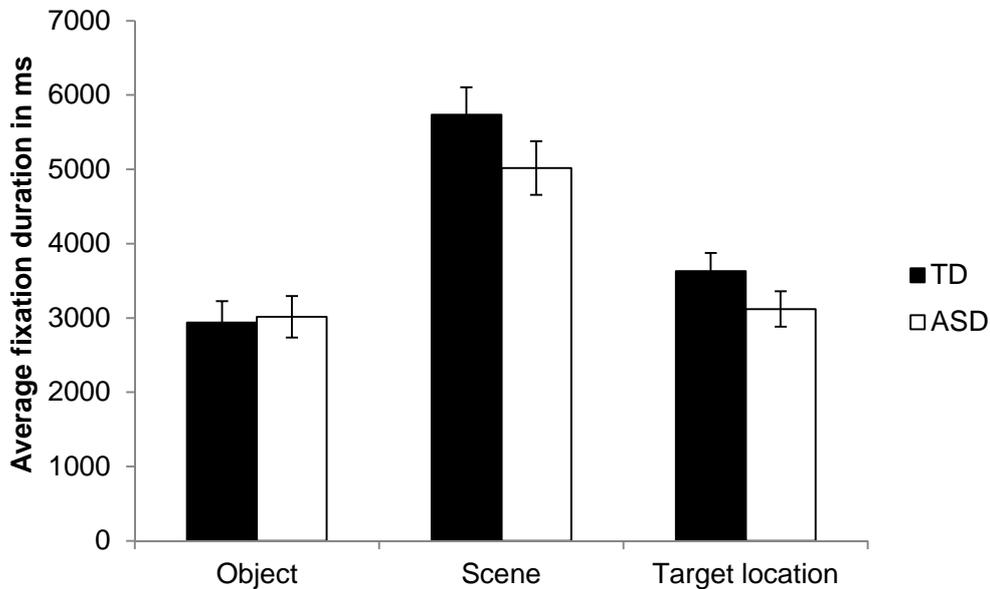
Figure 3.5. Average fixation duration in ms on ROIs during encoding of Experiment 2 for ASD and TD groups. The data are presented as mean $\pm$ SEM.

3.1.3.4.1.2   Eye-movement data sorted according to behavioural accuracy
To avoid a loss of eye-movement data because of ceiling effects in the behavioural memory data, separate 2 (Group [ASD, TD]) x 3 (ROI [Object, Scene, Location]) repeated measures ANOVAs were run for eye-movement data corresponding to correct and incorrect behavioural responses.

3.1.3.4.1.2.1   Data for correct trials
Eye-movement data for behaviourally correct trials are presented in Figure 3.6. Similarly to the analysis of all data (see Section 3.1.3.4.1.1), a significant main effect of *ROI*, $F(2,74) = 76.91$, $p < .0001$, $\eta_p^2 = .68$, with longer average fixations at the Scene compared to Object

and Location, $p_{max} < .0001$, Cohen's $d_{min} = 1.46$, 95 % $CI_{min}(0.95, 1.94)$, was found. There was no main effect of Group or Group x ROI interaction, $F_{max} < 1.66$, $p_{min} > .19$, $\eta_p^2{}_{max} < .05$.
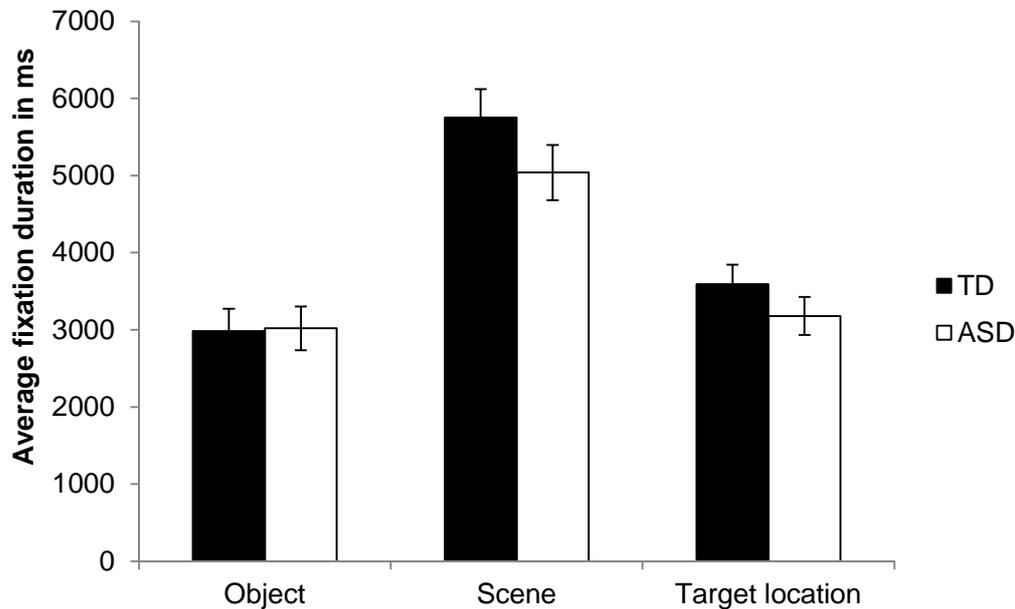
Figure 3.6. Average fixation duration in ms on ROIs during encoding for behaviourally correct trials for ASD and TD groups in Experiment 2. The data are presented as mean $\pm$ SEM.

3.1.3.4.1.2.2   Data for incorrect trials

The analysis for incorrect data (presented in Figure 3.7) showed significant main effects of *Group*, $F(1,28) = 6.58$, $p < .05$, Cohen's $d = 0.95$, 95 % $CI(0.16, 1.68)$, with shorter average fixations for the ASD compared to the TD group, and *ROI*, $F(1.65,46.25) = 27.62$, $p < .0001$, $\eta_p^2 = .50$, GGC, with longer average fixations at the Scene compared to the Location compared to the Object, $p_{max} < .01$, Cohen's $d_{min} = 0.78$, 95 % $CI_{min}(0.25, 1.30)$. A significant *Group x ROI* interaction, $F(1.65,46.25) = 4.15$, $p < .05$, $\eta_p^2 = .13$, GGC, showed that the ASD group fixated on average (marginally) less on the Scene ($M_{ASD} = 4254.85$, $SD_{ASD} = 1252.84$; $M_{TD} = 5694.55$, $SD_{TD} = 2825.49$), $p = .05$, Cohen's $d = 0.74$, 95 % $CI(-0.02, 1.46)$, and the

Location (M_{ASD} = 2592.72, SD_{ASD} = 836.36; M_{TD} = 4248.14, SD_{TD} = 1085.09), $p < .0001$,

Cohen's d = 1.85, 95 % CI(0.95, 2.66), compared to the TD group.
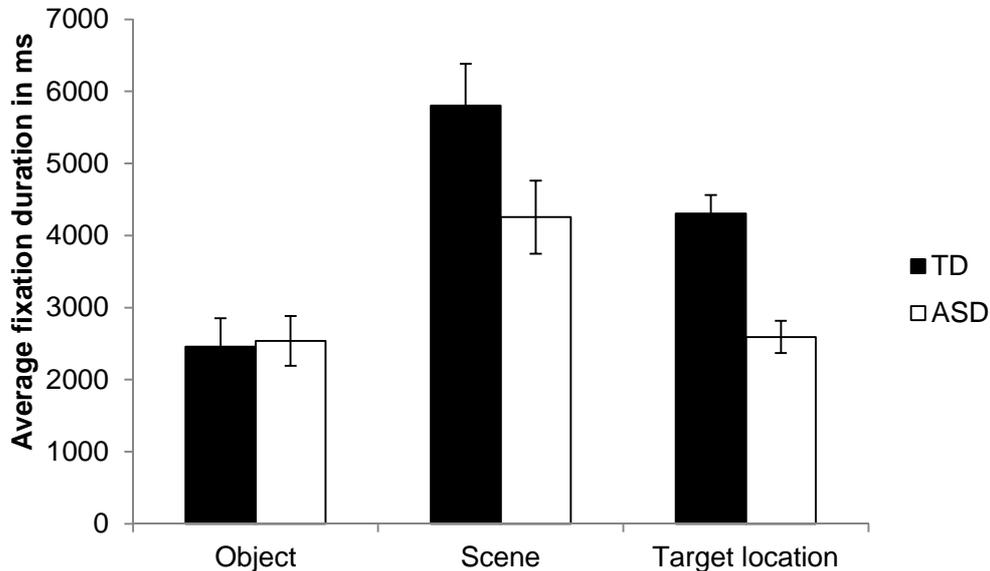
Figure 3.7. Average fixation duration in ms on ROIs during encoding for behaviourally incorrect trials for ASD and TD groups in Experiment 2. The data are presented as mean $\pm$ SEM.

3.1.3.4.2   Retrieval

3.1.3.4.2.1   Overall

To investigate differences in eye movements between the three phases of the test, the data were analysed using a 2 (Group [ASD, TD]) x 3 (Phase [Object-click, Location-click, Object in Location]) x 2 (Instruction [Include, Exclude]) x 2 (ROI [Target, Distracter]) repeated measures ANOVA, which showed a significant main effect of *Phase*, $F(1.19,44.04) = 227.66$, $p < .0001$, $\eta_p^2 = .86$, GGC, with the longest average fixations (in ms) in Location-click (M = 1156.50, SD = 405.77) compared to Object-click (M = 129.56, SD = 93.56) and Object in Location (M = 349.58, SD = 107.18), all $p < .001$, all Cohen's $d > 2.18$, 95 %

CI$_{min}$(1.61, 2.72). Therefore, all further analyses were run focussing on Location-click, which was also theoretically the phase of most interest as it corresponds to the time period of seeing the instructions and deciding which location to click on.

3.1.3.4.2.2 Retrieval Phase 2 - Location-click

The data, presented in Figure 3.8, were analysed with a 2 (Group [ASD, TD]) x 2 (Instruction [Include, Exclude]) x 2 (ROI [Target, Distracter]) repeated measures ANOVA. This showed significant main effects of *Instruction*, $F(1,37) = 37.02$, $p < .001$, Cohen's $d = 0.80$, 95 % CI(0.34, 1.26) and *ROI*, $F(1,37) = 65.06$, $p < .001$, Cohen's $d = 1.07$, 95 % CI(0.59, 1.54), with longer fixations during the Include compared to the Exclude conditions, and longer fixations on the Target compared to the Distracter locations. A significant *Instruction x ROI* interaction, $F(1,37) = 144.37$, $p < .001$, $\eta_p^2 = .80$, showed longer fixations on the Target compared to the Distracter locations for Include trials, and longer fixations for Distracter compared to the Target location for Exclude trials, all $p < .001$, all Cohen's $d > 1.65$, 95 % CI$_{min}$(1.13, 2.16). This interaction was expected given that the correct response during Include trials was the Target location, whereas during Exclude trials it was one of the Distracter locations. Of more interest was the observation of a significant three-way *Group x Instruction x ROI* interaction, $F(1,37) = 6.80$, $p < .05$, $\eta_p^2 = .16$, with a non-significant trend for shorter fixations on the Target location under the Include instruction for the ASD ($M = 1883.35$, $SD = 807.25$) compared to the TD group ($M = 2398.54$, $SD = 1037.27$), $p = .09$, Cohen's $d = 0.56$, 95 % CI(-0.09, 1.18), and significantly shorter fixations on the Distracter location under the Exclude instruction for the ASD ($M = 1142.72$, $SD = 371.07$) compared to the TD group ($M = 1465.94$, $SD = 542.77$), $p < .05$, Cohen's $d = 0.70$, 95 % CI(0.04, 1.33). No other main effects or interactions were significant, $F_{max} < 1.79$, $p_{min} > .18$, $\eta_p^2{}_{max} < .05$, including the main effect of Group.
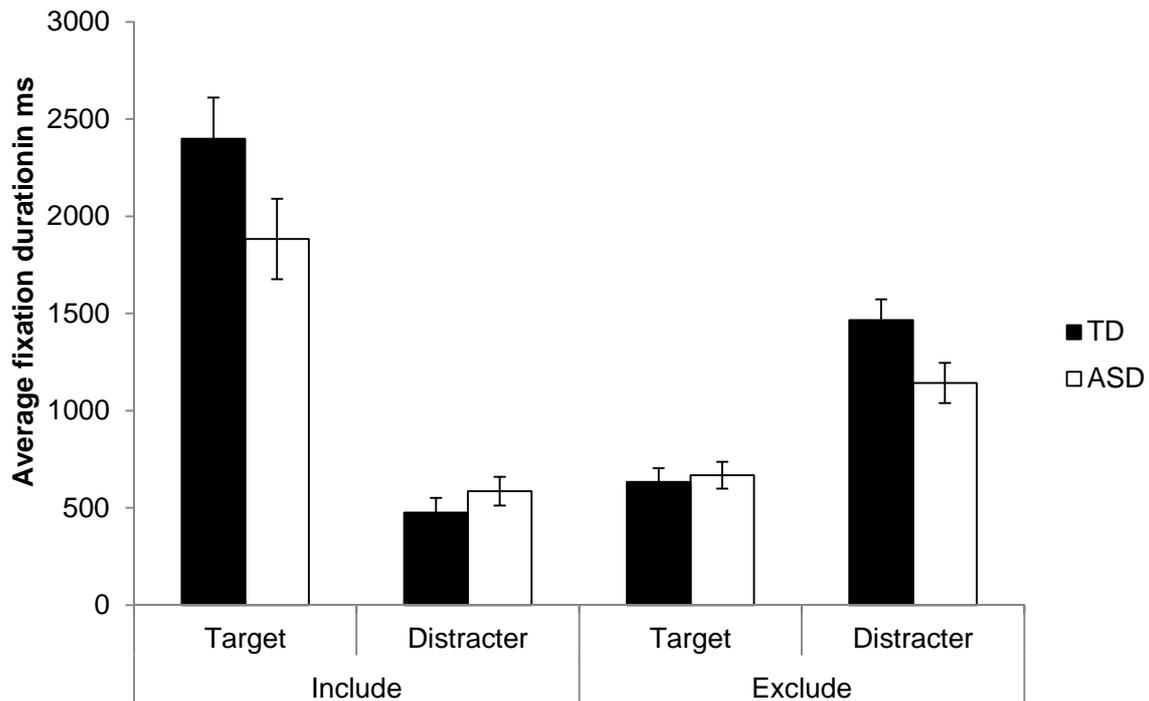
Figure 3.8. Average fixation duration in ms during retrieval Phase 2 (Location-click) for ASD and TD groups in Experiment 2, sorted by Instructions (Include - Old location; Exclude - New location) and ROIs. The data are presented as mean ± SEM.

3.1.3.4.2.3 Fixations on test trials presenting unstudied objects and their locations

To confirm that the above reported differences between conditions and groups reflect memory phenomena rather than differences caused by instructions, the participants' intention to select a certain image, or mere chance performance, fixations on target and distracter locations on include and exclude trials presenting unstudied objects and their locations (Figure 3.9) were examined using a 2 (Group [ASD, TD]) x 2 (Instruction [Include, Exclude]) x 2 (ROI [Target, Distracter]) repeated measures ANOVA. This showed a significant main effect of *Instruction*, $F(1,37) = 7.09$, $p < .05$, Cohen's $d = 0.23$, 95 % CI(-0.21, 0.68), with longer fixations on Include as opposed to Exclude trials, which may have just reflected participants effort in trying to remember whether they had previously studied a

location for this object. No other main effects or interaction were significant, $F_{max} < 1.37$, $p_{min} > .24$, $\eta_p^2{}_{max} < .04$.
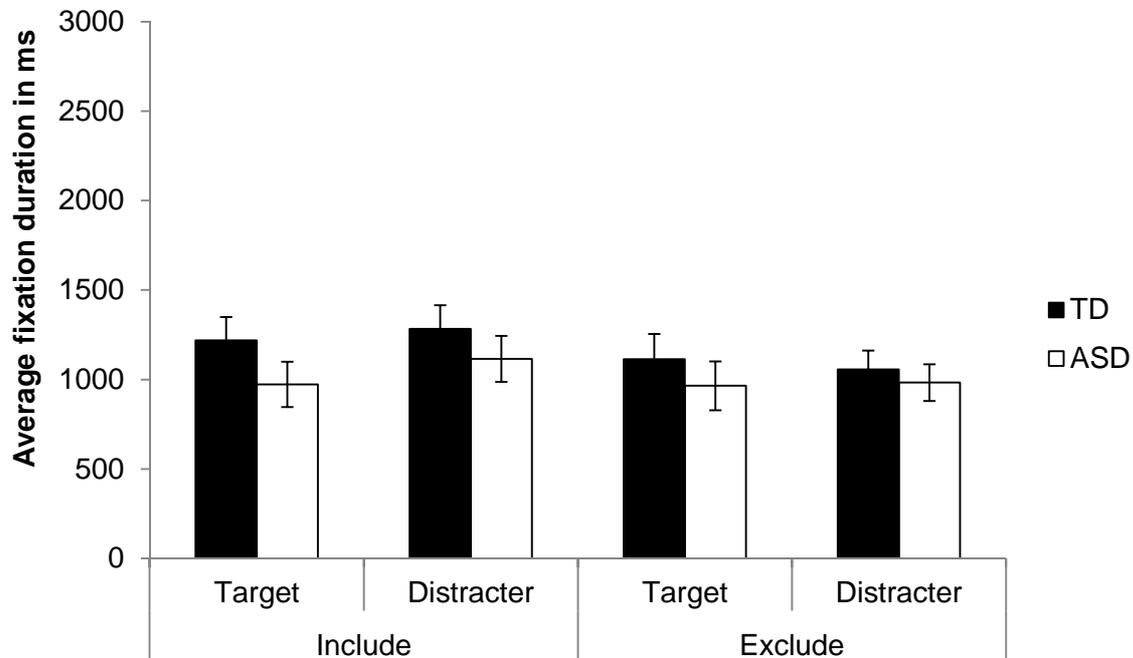
Figure 3.9. Average fixation duration in ms during retrieval Phase 2 (Location-click) for ASD and TD groups in Experiment 2, sorted by Instructions (Include - Old location; Exclude - New location) and ROIs for unstudied trials controlling for chance performance. The data are presented as mean $\pm$ SEM.

3.1.3.5 Correlations among behavioural and eye-movement data

3.1.3.5.1 Eye movements at encoding

To establish the extent to which fixation durations at encoding on Object, Scene, and Location may have contributed to later explicit and implicit memory[12] in the object-location memory task, bivariate correlations were calculated (Table 3.8). Fixation duration on the Scene at encoding was significantly positively related to subsequent implicit memory, in that

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[12] Analysing explicit and implicit relational memory for the reduced sample of participants for whom eye-movement data were available, led to the same results as the ones reported above.

the longer the Scene was fixated at encoding, the better later implicit memory was, which was especially the case for the TD group.

Table 3.8

Bivariate correlations between fixation duration at encoding and subsequent explicit and implicit relational memory in Experiment 2.

	Fixation Object			**Fixation Scene**			**Fixation Location**		
	ASD	**TD**	**Total**	**ASD**	**TD**	**Total**	**ASD**	**TD**	**Total**
Explicit	.12	-.43	-.04	.28	-.39	.17	.15	.00	.18
Implicit	-.21	.34	.10	.02	.69**	.38*	-.40	.39	.04

Note. *significant at $p < .05$. **significant at $p \leq .01$.

3.1.3.5.2 Eye movements at retrieval

To confirm that fixation durations at retrieval reflect a real memory phenomenon, eye movements were set in relation to behavioural data. Figure 3.10 plots the difference in fixation durations between target and distracter locations for the include condition against the proportion of times participants selected the target location as their answer in the include condition (correct behavioural response). The strong correlation between these variables ($r = .49$; $p < .01$; $r_{ASD} = .56$; $p_{ASD} < .05$; $r_{TD} = .25$; $p_{TD} = .31$) confirmed that eye-tracking data during retrieval provide valuable insight into memory processes. Further examination of relevant correlations within conditions (see Table 3.9) showed that, under both, include and exclude instructions, the proportion of times participants selected the target location was positively related to the fixation duration on that location. Conversely, fixation durations on distracter locations were negatively associated with the proportion of target location choices, although this was statistically reliable only for the include, but not the exclude condition.

Finally, actively retrieving the correct location was negatively related to fixation duration on the distracter under the include condition, and unconscious memory for the target location was positively related to fixation duration on the target under the exclude condition. Overall these data showed that participants' tendency to choose previously studied object locations was related to how much they attended to such locations, and to how much they averted attention from distracter locations.
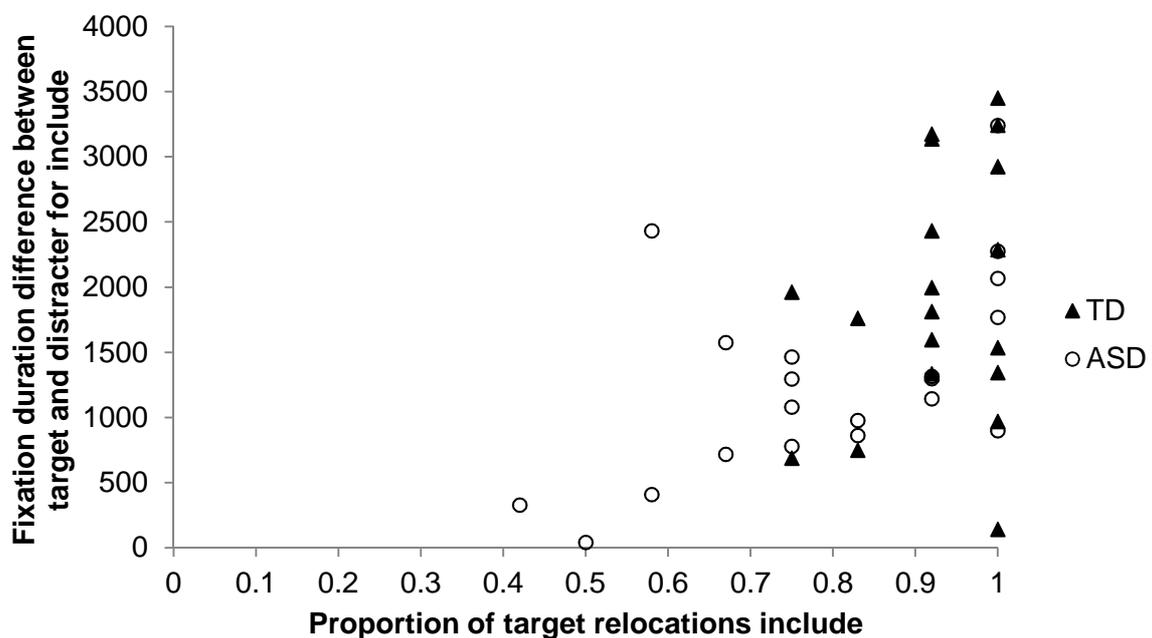
Figure 3.10. Association between the proportion of target relocations for the include condition and the difference in fixation durations between the target and distracter locations for include. The correlation illustrates that a greater propensity to look at the target vs. the distracter locations was related to the retrieval of the target location in the overt behavioural response.

Table 3.9

Bivariate correlations among behavioural and eye-movement data at retrieval in Experiment 2.

	Include-Tar[a]	Include-Dis[b]	Exclude-Tar[c]	Exclude-Dis[d]
Include[e]	.32*	-.43**	-.02	.17
Exclude[f]	-.06	.09	.34*	-.18
Explicit	.29[+]	-.39*	-.14	.21
Implicit	.15	-.21	.36*	-.12

Note. [a]Duration of fixation on the target location under the include condition. [b]Duration of fixation on the distracter location under the include condition. [c]Duration of fixation on the target location under the exclude condition. [d]Duration of fixation on the distracter location under the exclude condition. [e]Proportion of target relocations under the include condition. [f]Proportion of target relocations under the exclude condition. [+]$p < .1$. *significant at $p < .05$. **significant at $p \leq .01$.

Similar results were obtained when investigating correlations among behavioural memory accuracy and eye-movement data separately for the two groups (see Table 3.10).

Table 3.10

Bivariate correlations among behavioural and eye-movement data at retrieval separately for ASD and TD groups in Experiment 2.

	Include-Tar[a]		Include-Dis[b]		Exclude-Tar[c]		Exclude-Dis[d]	
	ASD	TD	ASD	TD	ASD	TD	ASD	TD
Include[e]	.28	.23	-.53*	.01	-.04	.17	-.01	.08
Exclude[f]	-.28	.28	-.01	.26	.23	.54*	-.55*	.25
Explicit	.33	.03	-.42[+]	-.14	-.12	-.17	.20	-.08
Implicit	-.08	.31	-.39	.13	.20	.62*	-.64**	.13

Note. [a]Duration of fixation on the target location under the include condition. [b]Duration of fixation on the distracter location under the include condition. [c]Duration of fixation on the target location under the exclude condition. [d]Duration of fixation on the distracter location under the exclude condition. [e]Proportion of target relocations under the include condition. [f]Proportion of target relocations under the exclude condition. [+]$p < .1$. *significant at $p < .05$. **significant at $p \leq .01$.

3.1.4 Discussion

The aim of the present study was to compare systematically explicit and implicit memory for relational daily life material using an externally validated paradigm, which enabled the assessment of both types of memory within the same task using similar instructions and the same processing requirements. Additional item memory tasks served to assess if item memory difficulties may contribute to relational memory difficulties in ASD. Through the measurement of eye movements it was aimed to bridge the gap between the distinctions of explicit and implicit and item and relational memory research in ASD, and to find out whether ASD individuals' relational memory difficulties are restricted to explicit retrieval in

direct tests, or whether the difficulties in ASD expand to implicit relational memory and are, therefore, also apparent in indirect tests. Identifying eye movements as a suitable measure of relational memory difficulties in ASD is of more general interest as these may be of potential use in a wider population of ASD individuals. Eye movements were also recorded to investigate the role of attention during encoding and to assess whether processing styles of ASD individuals may be related to memory difficulties. Finally, preliminary analyses were run to investigate the effect of age on explicit and implicit relational memory in both groups.

The task involved participants studying locations for objects in rooms, followed by a test of their memory for the objects' location, and them recognising objects and locations separately. Source memory tests were included examining recall of locations for remembered objects, and objects for remembered locations. It was predicted that, similar to TD OA, ASD individuals would show particular difficulties in explicit but not implicit relational memory in their behavioural responses. In addition, intact item and source memory performance was predicted for ASD individuals on object and location recognition tests, because these were supported tests for material that had been studied intentionally. Further, it was predicted that retrieval eye movements would show relational memory difficulties that would also be apparent in implicit relational memory, and that potential attention and scanning pattern differences between groups at encoding, as measured by eye movements, would contribute to a relational memory impairment in ASD.

The first prediction was supported. When looking at behavioural responses, ASD individuals showed lower explicit *relational* memory for the object locations in the presence of intact implicit relational memory. More specifically, ASD participants showed particular difficulties in placing an object into its previously studied old location, when presented with a choice of three locations. However, no difficulties occurred for choosing a new location for

the object. This finding confirmed previous results showing particular difficulties with explicit memory in ASD (Bowler et al., 1997; Gardiner et al., 2003; Renner et al., 2000), and extended them to relational material. It was also in line with findings in TD OA, showing difficulties with explicit but not implicit relational memory using the same task (Kessels et al., 2005b), supporting the ageing analogy of memory functioning in ASD (Bowler, 2007).

Regarding *item* memory, groups neither differed in object and location recognition, nor did they differ in source memory. These findings were in line with the relational memory account (Bowler et al., 2011), which predicts differences, specifically, for relational material in ASD. Considering the overall recognition memory deficit in ASD from Experiment 1, the current result of intact recognition memory seemed surprising. However, the recognition memory difference found in Experiment 1 resulted, particularly, from difficulties in Remembering in ASD, which relies on retrieving relational information, while Knowing in ASD was intact in Experiment 1. Although recollection and familiarity are both involved in R responses (Wais et al., 2008), these typically reflect responses largely based on recollection (Wixted & Mikes, 2010). Whereas in Yes/No tests, such as the item tests used in the current study, recollection and familiarity contribute similarly to a response, therefore, showing more intact performance in ASD (Yonelinas, 1999). Further, even source memory judgements that typically rely on recollection, are possible solely based on familiarity (Yonelinas, 1999). In addition, in the current study object, location recognition, and source memory were always tested after the object-location memory task, which may have prompted individuals to remember item and source information. This indicates task support, which has previously been reported to enable ASD individuals to perform better in memory tests (e.g., Bowler et al., 1997; 2004; 2008; O'Shea et al., 2005). More task support was provided in that recognition memory tasks (see also Section 1.4.1.3) had been used, and participants had been

instructed to study the requested information (locations for the object and objects for the location task - intentional encoding). Both would have improved task performance (Bowler et al., 2004; Souchay et al., 2013). Finally, as opposed to Experiment 1, where participants were instructed to remember any kind of context information, participants had been instructed, specifically, which information to report as source information for the current study, making the task potentially easier for them and increasing task performance for ASD individuals.

Difficulties with relational memory for the ASD group were also reflected in eye movements at *retrieval*, confirming the second prediction and showing that relational memory difficulties in ASD expand to implicit memory. ASD compared to TD participants showed shorter fixations on the locations they had to choose according to the instructions (target for include and distracter for exclude), indicating reduced memory for previously studied object-location relations through a reduced eye-movement-based relational memory effect (Althoff & Cohen, 1999; Ryan et al., 2007). This finding was in line with previous findings of impaired relational memory in ASD (e.g., Bennetto et al., 1996; Bigham et al., 2010; Bowler et al., 2014; Cooper et al., 2015; Gaigg et al., 2014; Poirier et al., 2011), which were now replicated with measures acting outside of conscious awareness. There were a number of observations that increased confidence in the conclusion that the differences between groups in eye movements at retrieval reflect real memory phenomena. Most importantly, there were significant correlations between behavioural data and fixation durations, for example, fixating the target as opposed to the distracter locations was significantly related to choosing the target location behaviourally. In addition, between-group differences in eye movements at retrieval were only found for previously studied items, confirming that the differences were not caused by instruction, intention, or chance. Further, similar response times for encoding and retrieval phases in the two groups and an absence of

a between-group difference for overall fixation duration suggest that the differences between conditions were not caused by longer encoding or retrieval in one group or an overall different quantity of eye movements. In addition, despite the differences between groups in the relational memory eye-movement effect, it was possible to find meaningful differences between conditions, in that both groups looked longer at the locations they were asked to choose compared to other locations, indicating that they understood the instructions and remembered the studied material. Therefore, it seems reasonable to argue that the measurement of eye movements is a useful technology for the study of cognitive processes such as memory in ASD. The technique is innovative and can be of great help to develop paradigms to find out more about cognitive functions in under-researched ASD populations, such as ID and/or minimally verbal individuals, who form the majority of individuals with the disorder (Baird et al., 2006). Moreover, using this technology may make it possible to investigate the development of cognitive functions such as memory in very young individuals with ASD.

Regarding *encoding*, the prediction was supported when looking at trials where participants made behavioural mistakes. As well as shorter overall fixation duration in the ASD group, a bias in the processing of specific information was found for ASD individuals in that they looked less at the relevant, i.e., the objects' location, and context information, i.e., the scene, which was in line with the finding from Loth et al. (2011), showing reduced attention to relevant details at encoding. When looking at the relation between fixation duration at encoding and subsequent explicit and implicit relational memory, it was found that implicit memory was positively related to fixation duration on the scene. It is possible that the reduced relational processing of the scene context in ASD may have contributed to impaired implicit relational memory, discovered through eye movements at retrieval.

From a memory point of view, these data added to a growing body of literature suggesting that next to the well-established differences in retrieval in ASD, differences during encoding contribute to the encountered memory difficulties. Differences in encoding in ASD have been reported previously in the context of item vs. relational strategies in behavioural memory tasks (Bowler et al., 2009; 2010; Gaigg et al., 2008; Southwick et al., 2011), and in brain activation during encoding (Gaigg et al., 2015). Alternatively or in addition, it may have been less the case that ASD individuals show difficulties in encoding material, but rather that because of a different attentional focus the information is put into the system in a different way. This interpretation fits with a bias to focus on local (detail) information, leaving the global context less attended to (WCC; Happé & Frith, 2006). Regarding this processing bias it is, however, important to note that ASD individuals have been found to be sensitive to global information despite a preference for details (Koldewyn et al., 2013; L. Wang et al., 2007). Similarly, the same individuals that showed a local bias in one task presented coexisting intact global performance in another task (Hadad & Ziv, 2015; Plaisted et al., 1999; Rondan & Deruelle, 2007). For processing faces it has been found that it was possible to train ASD individuals to use a global processing style in favour of a local style (Chabani & Hommel, 2014). These findings led Plaisted et al. (1999) to conclude that ASD individuals seem to need explicit instructions in order to process information globally. This is an argument that is in line with the task support hypothesis (Bowler et al., 1997), which states that with the provision of task support, for example, specific encoding instructions, ASD individuals are able to show better performance. It, therefore, remains an important task for future research to test whether, providing specific task instructions that change the attentional focus of ASD individuals to guide their attention to the relevant

information, their memory difficulties can be overcome or whether memory difficulties remain despite attentional guidance.

The data just reviewed, taken together with correlations among behavioural tasks, enable speculations about underlying brain regions. Correlations among explicit memory tasks may reflect the dependence on similar brain regions, such as the hippocampus for object-location and source memory (Cansino, Maquet, Dolan & Rugg, 2002; Postma et al., 2008b), the PFC for recognition and source memory, and the parietal cortex for recognition and object-location memory (Postma et al., 2008b). The expression of memory in eye movements has been found to be related to activity in the hippocampus and PFC (Hannula & Ranganath, 2009), and attentional processes underlying differences found in eye movements during encoding, were found to be related to functions of the MTL, PFC, as well as the parietal cortex (Cabeza et al., 2008). Even unconscious relational encoding has recently been found to be a function of the hippocampus (Duss et al., 2014). In line with the ageing analogy (Bowler, 2007), abnormalities in fronto-hippocampal functions have been shown in both TD OA (Hedden & Gabrieli, 2004), as well as ASD (Gaigg et al., 2015), which may be involved in their relational memory difficulties. Inspecting behavioural findings, TD OA showed difficulties in both conditions of the object-location memory task (Kessels, et al., 2005b), whereas ASD individuals in the present study struggled with the include condition only. A ceiling effect in the current study may have masked a between-group difference in exclude trials. However, it is also possible that memory difficulties in ASD are less pronounced than those in TD OA (as suggested by Boucher, Mayes & Bigham, 2012; Bowler et al., 2010), which was already suggested by Experiment 1, where age had a slightly stronger effect on TD as opposed to ASD individuals memory. It is also possible, that memory difficulties and the effects of age on memory are more pronounced in ASD than in TD OA and the finding of

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intact source memory in ASD in the current study may reflect a compensatory mechanism. Since source memory has also been found to depend on frontal lobe functions (Craik, Morris, Morris & Loewen, 1990), ASD individuals may recruit these to overcome difficulties related to hippocampal dysfunction (as already suggested by Maister et al., 2013). This may be possible because (memory) atypicalities in ASD result from an atypical developmental trajectory, where connections between brain regions get formed differently, whereas dysfunction in TD OA and patients with hippocampal damage occur after a period of typical development. In line with the idea of more pronounced memory difficulties in ASD with age was the finding from the exploratory regression analysis in the current study, showing that explicit memory was much more affected by age in ASD as opposed to TD individuals. This observation was in line with the *double jeopardy* hypothesis (Geurts & Vissers, 2012), and the fact that when followed up longitudinally, 25 % of ASD individuals' cognitive functions declined to such an extent that it prevented them from taking part in further research (Howlin, Savage, Moss, Tempier & Rutter, 2014). It contradicted, however, the results form Experiment 1 and another recent study (Lever & Geurts, 2016), showing a reduced effect of age on memory in ASD. There are a few possible explanations. It is possible that slightly different groups of participants were recruited for Experiments 1 and 2, and that the ASD group in the current experiment was, particularly, vulnerable to the effects of age on memory. This interpretation seems, however, unlikely since the ASD groups recruited for both experiments were rather similar in variables, such as IQ, age, gender, AQ, and ADOS. A more likely explanation is that a ceiling effect in the current study in the TD group may have obscured the effects of age on TD individuals' memory performance. The biggest difference between the memory results in Experiment 1 and the current study was the fact that in the current study younger ASD and TD individuals performed similarly, and only the older

individuals in both groups differed, whereas in Experiment 1, younger ASD individuals already performed at a much lower level than younger TD individuals. To conclude, more research is needed into the effects of age on memory and other cognitive functions in ASD. Taking the behavioural and eye-movement findings together, they further added to Maister et al. (2013)'s suggestion to consider the involvement of hippocampus, PFC, and parietal cortex in the cognitive and memory difficulties in ASD. Abnormalities in these brain regions may, however, differ from those observed in other disorders.

Some final comments are needed about the methods used in this study. The conclusions of the present study rely heavily on the *PDP* (Jacoby, 1991), which has attracted some criticism. First, using the PDP in within-subject comparisons would be problematic because participants performing perfectly in include and exclude conditions would lead to an underestimation of the explicit memory component (Buchner et al., 1995), which may be avoided by dropping perfectly performing participants from the analysis. Doing this in the current study, left the results unchanged. Second, Graf and Komatsu (1994) suggested the complexity of the include and exclude instructions may make it difficult for participants to perform them after one another within one test phase. To reduce difficulties, participants in the current study were asked to read out loud the instructions for every trial to ensure that they followed them and were paying attention. Third, Buchner et al. (1995) argued that calculating explicit and implicit memory scores from only a few values would create high standard errors for every participant, masking between-group differences. However, a substantial effect was still found in the current study. Fourth, two other criticisms of the PDP relate to the assumption that implicit and explicit memory are working independently of one another (Curran & Hintzman, 1995), and that the original procedure does not take correct guesses into account (Buchner et al., 1995). To face both criticisms a multinomial model was

devised (Buchner et al., 1995; Caldwell & Masson, 2001), and applying this to the data reported in the current study left the results unchanged.

Finally, the sample size may be regarded as small and the number of analyses performed may have increased the risk of Type I errors. In addition, the interpretation of the behavioural results was hampered by ceiling and floor performance in some individuals. The use of eye-movement measures helped to overcome problems of ceiling and floor effects, and difficulties in implicit relational memory in ASD were found that were not established with behavioural measures. However, further research is needed to replicate the findings of this study.

Overall, the present study extends our understanding of reduced relational memory in ASD by showing that difficulties expand to the area of implicit memory. Differences in relational memory retrieval seem to be accompanied by differences in encoding that are guided by attentional processes biasing ASD individuals' focus away from relevant and context information. Both, Experiments 1 and 2, have highlighted the utility of eye-movement and pupil size measures in studying cognitive processes in ASD. These measures should, therefore, be considered more often when testing cognitive functions in ASD, especially because their use requires minimal verbal instructions, enabling the use in a broader ASD population. A few questions remain unanswered. These will be tackled in the next experiment. It is unclear what role the factors of language and previous experience with daily objects and their locations in participants' homes may have played in the current study. Also uncertain is which other relations are difficult for ASD individuals, and which relation(s) are most difficult. And finally, it is of interest to examine whether item memory remains intact when tested with a task of similar complexity as a relational memory task and if such an investigation resolves the discrepancies between Experiments 1 and 2.

3.2 Experiment 3: Relational memory for location, temporal order and set

3.2.1 Introduction

3.2.1.1 Theoretical background

Regarding the distinction between *item* memory, which concerns memory for single units of material with one meaning (Cohen et al., 1997) and *relational* memory, which constitutes memory for contextual information, such as time, place, or relations among items (Davachi, 2006; Sections 1.3.2, 3.1.1.1), Experiment 2 found specific difficulties with relational memory and intact item memory in ASD compared to TD individuals. Most previous research reported intact item memory. However, some previous studies also reported difficulties in item memory in ASD as opposed to TD (Bowler et al., 2004, 2016; Cooper et al., 2015; Semino et al., in preparation), for example, when less support was provided at test, or when participants needed to use meaning that was inherent in the study materials (see Section 1.4.1.3). Relational memory has been reported more difficult for ASD as opposed to TD individuals, such as remembering the locations (Bowler et al., 2004, 2014; Cooper et al., 2015; Semino et al., in preparation; Experiment 2), colours (Massand & Bowler, 2015), temporal order (Bennetto et al., 1996; Bigham et al., 2010; Bowler et al., 2016; Gaigg et al., 2014; Ni Chuileann & Quigley, 2013; Poirier et al., 2011), or lists items were presented in at study (Bennetto et al., 1996; Minshew & Goldstein, 1993). Only two previous studies have compared different types of relational memory directly in ASD. Both found similar ASD-related difficulties for remembering screen-locations or the gender of a speaker presenting words (Bowler et al., 2004), and for colours or locations of line drawings that were presented in a grid on a computer screen (Bowler et al., 2014). The question remains whether remembering other relations, such as the temporal order of presentation, or which items were

presented together in a set at study, is similarly difficult as these other relations for ASD participants.

What remains problematic when comparing research on item and relational memory is that item memory tests usually involve the judgement whether a single item was studied previously or is new to the participant, whereas relational memory tests require a judgement if multiple items were studied in a particular configuration or not. Relational compared to item memory tests have, therefore, higher processing requirements because of the number of discrete units of information presented to the participant and the number of relations that need to be formed among these units, which is problematic for a direct comparison between item and relational memory, especially if one considers ASD as a disorder of complex information processing (Minshew & Goldstein, 1998). Inconsistencies in the literature on item memory may, therefore, be related to the factor of relational processing requirements in that some item memory tasks place higher demands on relational processing than others do. To resolve this issue, systematic investigations of item and relational memory are needed using tasks that place similar demands on relational processing.

There are six existing investigations comparing item and relational memory in ASD within the same task. These show inconsistent results. Whereas Bowler et al. (2014) found intact memory for items, i.e., pictures, colours, locations, but difficulties remembering the combinations, i.e., items in colours, items in locations, Massand (2011, Experiment 5) found similar difficulties for remembering line-drawings as well as their colours. Although the main effect of group in Massand (2011) only came close to significance, effect sizes for the group differences in item and relational tasks were similarly large. Similar difficulties in ASD were found for remembering pictures of daily objects (Semino et al., in preparation) or words (Bowler et al., 2004), and their screen locations or the gender of the speaker that presented

words at study (Bowler et al., 2004). Bowler et al. (2016) recently reported similar difficulties in remembering locations for dots in a grid as well as the temporal order of their presentation. Finally, Cooper et al. (2015) found similar difficulties in item and relational memory tests by changing items or locations for an item in a scene. Therefore, most previous studies would suggest similar difficulties in item as well as relational memory in ASD when tasks are used that place similar requirements on relational processing.

However, none of these previous studies has considered the influence of the use of different materials or other factors such as language on memory. As has been shown in Experiment 1, memory for pictorial material is superior over memory for verbal material in ASD, similarly as it is in TD individuals. All of the investigations just described (except Bowler et al., 2016) used either verbal materials or pictures with verbal labels and, as such, were potentially confounded by language abilities (e.g., Baird et al., 2006), and verbal strategies such as the use of sub-vocal and inner speech strategies (D. M. Williams et al., 2012) that have previously been reported to differ between groups. In addition, previous experience with the studied materials may have differed between groups, which would not be the case had novel abstract shape images been used.

In a direct comparison between memory for items and different types of relations (serial order, spatial locations, item-associations) in patients with hippocampal as well as wider MTL lesions (Konkel, Warren, Duff, Tranel & Cohen, 2008), similar difficulties in different types of relational memory were found for patients as opposed to control participants. In addition, while patients with hippocampal lesions performed at chance on the three relational memory tests, they performed above chance on the item memory test, albeit at a significantly lower level than the TD group. Patients with MTL lesions performed at chance on all tasks (Konkel et al., 2008). Following Konkel and Cohen (2009), different types of

relational memory should be similarly difficult since they rely to the same extent on the same brain region, namely the hippocampus.

Having reviewed the relevant literature, the aims for the current study were the following. First, it was aimed to compare different types of relational memory in ASD using the same paradigm. In addition, it was of interest to compare relational memory to memory for items using the same paradigm placing the same demands on relational processing. Through the use of abstract shape images, it was aimed to minimise the influence of language and previous experiences with the study materials on memory in the current study. Third, it was aimed to examine the criteria on which both groups of participants base their recognition memory judgements. Finally, the examination of the effects of age on item and relational memory in ASD and TD individuals was of interest.

Based on these aims, a paradigm was chosen that had been developed, specifically, to examine item as well as different types of relational memory using the same procedure (Konkel et al., 2008). The task required participants to study abstract shape triplets, as well as their relations. Each shape of a triplet was presented in a specific screen location, shapes were presented in a specific order, and three shapes formed a set of shapes. At test, memory for the shapes, the spatial locations, the temporal order, or the sets of shape presentation was tested using separate item and relational tests, either manipulating which items were presented on the screen or the relations among the items, or keeping them the same as at study. Participants were asked to indicate whether the items or the relations were the same as at study or whether they had changed.

To test the aims, corrected recognition rates were examined. If ASD individuals show difficulties with relational memory, they will show reduced memory performance in the relational tasks as opposed to TD individuals. In addition, there will be no significant

difference in performance between the different relational memory tasks. If ASD individuals show intact item memory, they will not show reduced performance on the item task. However, if ASD participants struggle, particularly, with the relational processing requirements of the task, also item memory should be reduced compared to TD participants. To follow the third aim, FA rates, sensitivity, and response criteria were examined. If, similarly to Experiment 1, ASD participants show difficulties in distinguishing between old and new materials, they will show higher FAs, lower sensitivity and response criteria compared to TD participants. Finally, regarding the effect of age on memory, if ASD individuals' memory is similarly affected by age as that of TD individuals, persons with ASD will show effects of age on relational but not item memory.

3.2.1.2 Predictions

Based on the evidence outline above, it was predicted that ASD individuals would show particular difficulties with the relational memory tasks. The same predictions would follow from theories suggesting a relation between memory difficulties in ASD and hippocampal pathology (see Section 1.4.2.1), which would suggest that ASD participants would perform similarly to hippocampal lesioned patients (Konkel et al., 2008). Because of the inconsistencies found in Experiments 1 and 2 regarding the effect of age on memory in ASD and TD individuals, and because of the lack of findings on memory in TD OA with a paradigm such as the one used by Konkel et al. (2008), it was of interest to explore the effects of (older) age on item and relational memory in this study. Possible outcomes were stronger (*double jeopardy* - Geurts & Vissers, 2012; Experiment 2), weaker (*safeguard hypothesis* - Geurts & Vissers, 2012; Lever & Geurts, 2016; Experiment 1), or similar (*parallel development* - Geurts & Vissers, 2012) age-related memory differences in ASD compared to TD adults in the current study.

3.2.2 Methods

3.2.2.1 Participants

Konkel et al. (2008) tested 10 control participants and seven amnesic patients, four with hippocampal lesions and three with a lesion to the wider MTL. Based on the data for control participants and hippocampal patients provided by A. Konkel (personal communication, August 8, 2016), power calculation using G*Power (Faul et al., 2007) showed that to detect a significant Group x Task interaction with an effect size of $f = 0.57$ and a statistical power of 0.90, a total sample size of eight participants would be needed. To increase statistical power because ASD samples are often heterogeneous, 18 TD (14 men, $M_{age} = 43.48$ years, age range: 23-61 years) and 18 ASD adults (13 men, $M_{age} = 42.78$ years, age range: 20-62 years) were tested. They were individually matched on VIQ, PIQ, and FIQ, as measured by the WAIS-III^{UK} (The Psychological Corporation, 2000). Groups were closely matched on gender, and CA, and ASD individuals had significantly higher scores on the AQ (Baron-Cohen et al., 2001; see Table 3.11).

Table 3.11

Descriptive statistics for ASD and TD individuals, who participated in Experiment 3.

| Measure | ASD (13m, 5f) | | TD (14m, 4f) | | | | Cohen's | |
	M	*SD*	*M*	*SD*	*t*(34)	*p*	*d*	CI
Age (years)	42.78	11.8	43.48	13.0	0.17	.87	0.06	-0.60, 0.71
VIQ[a]	109	15.8	111	15.6	0.47	.64	0.13	-0.50, 0.81
PIQ[b]	104	20.1	105	18.0	0.06	.95	0.05	-0.63, 0.67
FIQ[c]	108	17.9	109	17.2	0.29	.77	0.06	-0.56, 0.75
AQ[d]	33.56	7.0	15.28	6.7	7.99	.00	2.66	1.72, 3.49
ADOS-C[e]	2.60 (0-6)	1.6						
ADOS-RSI[f]	6.00 (1-13)	3.3						
ADOS-Total[g]	8.60 (3-17)	4.1						
ADOS-I[h]	1.27 (0-2)	0.8						
ADOS-SB[i]	1.2 (0-3)	0.9						

Note. [a]Verbal IQ (WAIS-III[UK]). [b]Performance IQ (WAIS-III[UK]). [c]Full-scale IQ (WAIS-III[UK]). [d]AQ - Autism-Spectrum Quotient. [e]ADOS - Communication subscale. [f]ADOS - Reciprocal Social Interaction subscale. [g]ADOS Total score - Communication + Reciprocal Social Interaction. [h]ADOS - Imagination/Creativity subscale. [i]ADOS - Stereotyped Behaviours and Restricted Interests subscale. For ADOS scores, range of scores in brackets.

Time permitted to examine 15 ASD participants with the ADOS (Lord et al., 1989). Five of these scored just below the total cut off-score, but were nevertheless included in the sample since they all had received a clinical diagnosis of an ASD before the study. Because comorbidities and medication use were found to be a common feature of the disorder (Croen et al., 2015; Esbensen et al., 2009; Section 2.1.2.1), ASD individuals that reported comorbid

disorders and/or taking psychotropic medication were included in the sample. In the current study, 17 % of ASD participants reported comorbidities and/or psychotropic medication use. Depression (67 %), ADHD (33 %), OCD (33 %), schizophrenia (33 %), and dyslexia (33 %) were most common. In addition, 33 % of ASD participants took antidepressants, and 33 % reported taking antipsychotic medication. ASD individuals with and without comorbidities and medication use did not differ significantly in terms of gender, $X^2 = 0.06$, $p = .81$, CA, VIQ, PIQ, and FIQ, $t_{max} < 0.79$, $p_{min} > .44$, Cohen's $d_{max} < 0.48$, 95 % $CI_{max}(-0.78, 1.72)$. Again, analysing the data without ASD individuals that reported comorbidities and/or medication use left the results reported below unaffected.

3.2.2.2 Materials

Materials were 356 (eight for practice task) black abstract shape images, previously used in perception (Haenschel et al., 2007) and memory studies (Experiment 1) in clinical populations, making them suitable materials. They had been generated with a Matlab algorithm to achieve comparable levels of complexity for all shapes. In the current study, they were presented on a grey square measuring 5.3 cm x 5.3 cm on a white screen background on a 20 inch desktop monitor (see Figure 3.11 for examples).
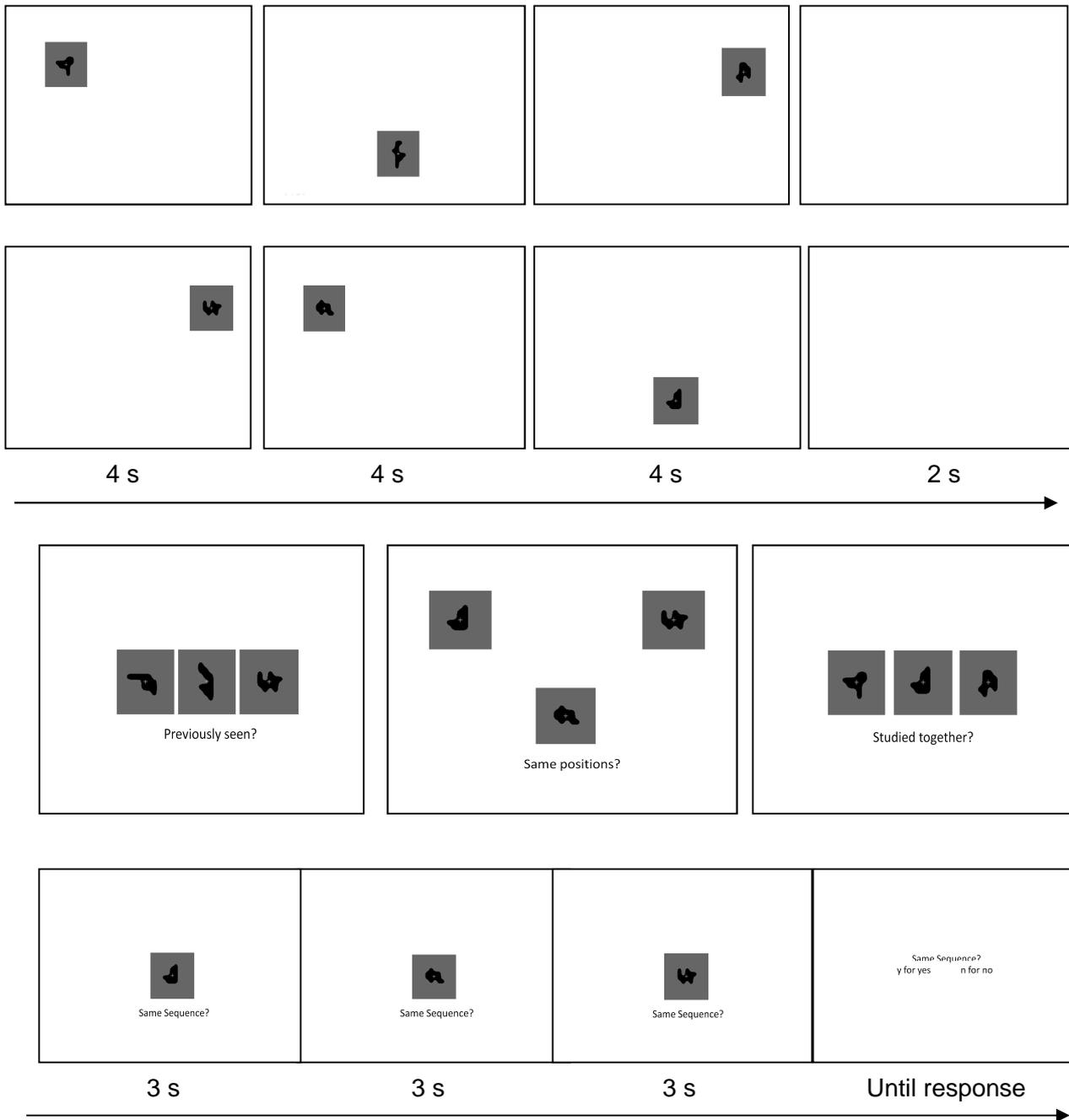
Figure 3.11. Examples of two study trials (top) and manipulated test trials (middle and bottom) for Experiment 3. Figure 3.11a (middle left) shows an item test trial presenting one item from study Trial 2 with two previously unseen items. Figure 3.11b (middle middle) shows a location test trial with images from study Trial 2 with the images top left and bottom middle in swapped locations. Figure 3.11c (middle right) shows an associative test trial presenting two images from study Trial 2 intermixed with one image from Trial 1. Figure

3.11d (bottom) shows an order test trial presenting images from study Trial 2 with the first and the third image in swapped positions in the sequence.

3.2.2.3 Procedure

The paradigm used by Konkel et al. (2008) was adapted with the following changes. First, presentation time was increased and the number of images was reduced because the timings and number of images of the original procedure proved too difficult in a number of pilot studies. Instead of coloured images, black shapes were used because a recent review of vision in ASD (Simmons et al., 2009) indicated difficulties in remembering and discriminating between different colours in ASD compared to TD individuals. Finally, to avoid that ASD individuals would pay attention to irrelevant information and, therefore, would show difficulties in this task, participants were instructed which information to remember in a particular task, i.e., item, location, order, or set information.

The task was presented on a computer screen using E-Prime software, and responses were collected through a keyboard. Participants were given the chance to ask questions, and they were told that the task was quite difficult, and, therefore, they were encouraged to take as many breaks as they needed. Total task duration (in minutes), including breaks, did not differ significantly between ASD (M = 79.39, SD = 47.19, range: 48-213) and TD (M = 66.28, SD = 16.41, range: 48-110) groups, $t(34)$ = 1.11, p = .27, Cohen's d = 0.37. After some practice in the form of an item test with one repeated (the same items as at study) and one manipulated test trial (one studied shape was presented together with two new shapes), participants took part in four tasks consisting of eight (item, location, order task) or 12 (associative task) study-test blocks. In all study blocks, participants saw three unique sets of abstract shape triplets, chosen at random from a master set of 356 stimuli. Each triplet (image set) was presented once, with a presentation time of 4 s for each item, and a 2 s blank screen

following each triplet (see Figure 3.11 top part). The shapes of a triplet were presented in succession in each of three screen-locations: top left, top right, and bottom middle of the screen. The order of screen locations was counterbalanced across the three study triplets, such that each location was once first, second, and third to be occupied by a shape. Right after each study block, three test trials (two for the associative task[13]) followed, presenting items together with a test question, which remained on the screen until participants gave their response (see Figure 3.11 middle and bottom part). Test trials were either *repeated* trials, in which the items and/or relations between the items were the same as at study, or *manipulated* trials, presenting new items or changed relations between familiar items. Overall, participants took part in 12 repeated and 12 manipulated test trials for each task, which were presented in counterbalanced order across all blocks for a particular task. All participants received the item test first, in order to avoid that they would employ relational strategies, learned through the relational tasks, in the item test. The order of the three relational tasks was counterbalanced across participants with each matched pair of participants (one ASD and one TD individual with similar IQs) receiving the same presentation order. Except for the order test, all tests involved the simultaneous presentation of three shapes in the centre of the screen together with a test question. In *item test* trials, participants either saw the same shape triplets as at study (*repeated* trials), or one familiar shape was presented together with two entirely new shapes (*manipulated* trials), and participants were asked if they had seen all three items previously, or if one or two of the shapes seemed new to them (Figure 3.11 middle left). For all relational tests, participants were told that none of the items would be new. In *location test* trials, either three shapes occupied the same locations as at study (*repeated* trials), or two of the shapes had swapped their locations (*manipulated* trials), and participants were asked to

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[13] Participants were only presented with two associative test trials (one repeated and one manipulated) in each block to avoid shape repetition. Shapes from two study triplets had been mixed to create one manipulated test trial.

indicate whether all three shapes were presented in the same positions as at study (Figure 3.11 middle middle). For *associative test* trials, participants either saw the three shapes from the same triplet as at study (*repeated* trials), or shapes from two study triplets were mixed (*manipulated* trials), and participants were asked whether they had studied these three shapes together in the same triplet (Figure 3.11 middle right). Finally, for the *order test* a sequence of three shapes, each shown in the centre of the screen, was presented either in the same order as at study (*repeated* trials), or two shapes had swapped their serial position (*manipulated* trials), and participants were asked to indicate whether the order of the shapes was the same as at study (Figure 3.11 bottom).

3.2.3 Results

The data were scored in terms of Hits (percentage of correct yes answers on repeated trials), FAs (percentage of incorrect yes answers on manipulated trials), and corrected recognition rates (Hits minus FAs). Results were analysed using Chi-Squared tests, one sample and independent samples t-tests, repeated measures ANOVAs, bivariate correlations, and linear regression analyses. GGC was used, when the Sphericity assumption was violated. The level of significance was set to .05, and Cohen's *d* and partial Eta-Squared are reported as effect size measures.

3.2.3.1   Accuracy

All data presented in this section were analysed using 2 (Group [ASD, TD]) x 4 (Task [item, location, order, associative]) repeated measures ANOVAs.

3.2.3.1.1 Corrected recognition

Corrected recognition data (see Figure 3.12; Table 3.12) showed a significant main effect of *Group*, $F(1,34) = 12.66$, $p < .01$, Cohen's $d = 1.19$, 95 % CI(0.45, 1.87), with higher performance for the TD compared to the ASD group. A significant main effect of *Task*, $F(3,102) = 9.51$, $p < .001$, $\eta_p^2 = .22$, indicated higher performance in the *item* compared to *order*, $p < .05$, Cohen's $d = 0.54$, 95 % CI(0.06, 1.00), and *associative* tasks, $p < .001$, Cohen's $d = 0.95$, 95 % CI(0.46, 1.43), and higher performance in the *location* compared to the *associative* task, $p < .05$, Cohen's $d = 0.62$, 95 % CI(0.14, 1.09). There was no Group x Task interaction, $F(3,102) = 0.64$, $p = .59$, $\eta_p^2 = .02$.
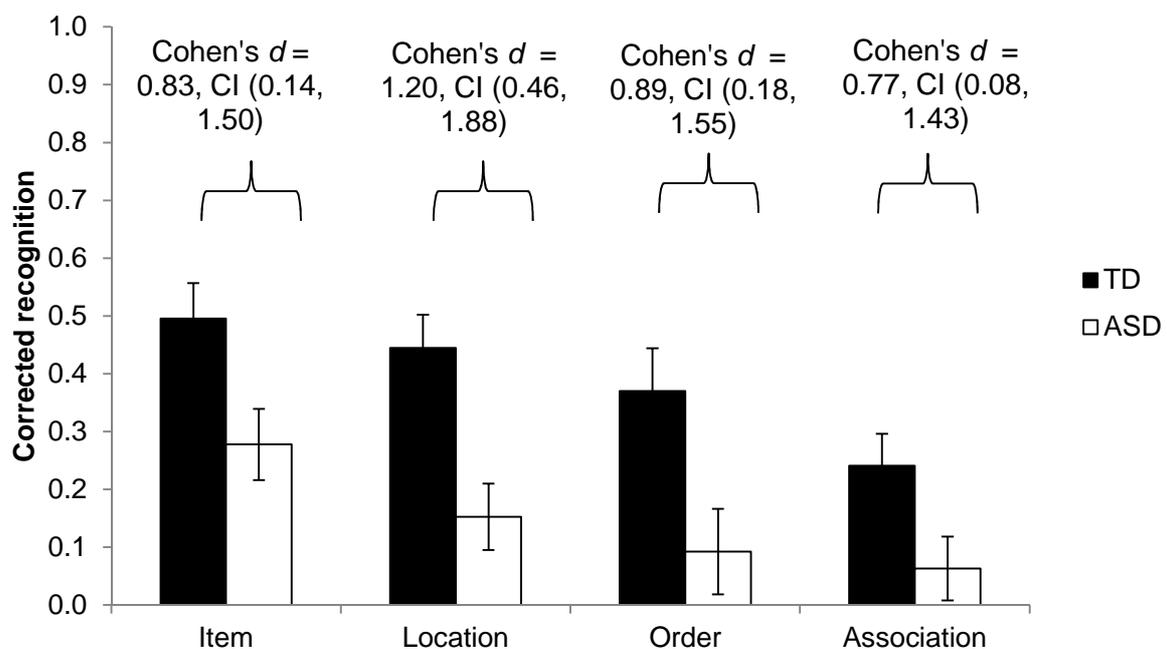
Figure 3.12. Corrected recognition scores (Hits minus FAs) for the four tasks of Experiment 3 comparing ASD and TD groups, including effect sizes (Cohen's *d*) for the between-group differences. The data are presented as mean ± SEM.

Table 3.12

Means and Standard Deviations for Hits, FAs, and Corrected recognition rates (Hits minus FAs) for the four tasks for ASD and TD groups in Experiment 3.

Measure	ASD M (SD)	TD M (SD)	Total M (SD)
Hits	0.51 (0.23)	0.60 (0.21)	0.55 (0.23)
Item task	0.56 (0.27)	0.65 (0.18)	0.60 (0.23)
Location task	0.50 (0.18)	0.58 (0.21)	0.54 (0.20)
Order task	0.49 (0.22)	0.57 (0.27)	0.53 (0.25)
Associative task	0.50 (0.26)	0.58 (0.17)	0.54 (0.22)
FAs	0.36 (0.22)	0.21 (0.19)	0.29 (0.22)
Item task	0.28 (0.23)	0.15 (0.20)	0.22 (0.22)
Location task	0.35 (0.21)	0.14 (0.13)	0.24 (0.20)
Order task	0.39 (0.22)	0.19 (0.16)	0.29 (0.21)
Associative task	0.44 (0.22)	0.34 (0.19)	0.39 (0.21)
Hits-FAs	0.15 (0.23)	0.39 (0.31)	0.27 (0.30)
Item task	0.28 (0.22)	0.50 (0.30)	0.39 (0.28)
Location task	0.15 (0.23)	0.44 (0.25)	0.30 (0.28)
Order task	0.09 (0.26)	0.37 (0.36)	0.23 (0.34)
Associative task	0.06 (0.17)	0.24 (0.28)	0.15 (0.25)

Because of the difficulty level of the tasks, performance was compared against chance. The chance level of 0 for corrected recognition was calculated by subtracting FAs (chance level 0.5) from Hits (chance level 0.5 and 0.5-0.5 = 0). Whereas the TD group performed above chance in all four tasks, all $p < .01$, the ASD group was at chance in the *order*, $t(17) = 1.51$, $p = .15$, and *associative* tasks, $t(17) = 1.47$, $p = .16$.

3.2.3.1.2 False Alarms

FA rates (Table 3.12) were analysed to investigate whether the group differences observed were related to differences in response criteria. The analysis showed a significant main effect of *Group*, $F(1,34) = 8.46$, $p < .01$, Cohen's $d = 0.97$, 95 % CI(0.26, 1.64), with higher FA rates for the ASD compared to the TD group, and a significant main effect of *Task*, $F(2.42,82.29) = 12.20$, $p < .001$, $\eta_p^2 = .26$, GGC, with higher FA rates in the *associative* compared to all other tasks - *item, $p < .001$*, Cohen's $d = 0.83$, 95 % CI(0.34, 1.30), *location*, $p < .01$, Cohen's $d = 0.77$, 95 % CI(0.28, 1.24), and *order*, $p < .05$, Cohen's $d = 0.48$, 95 % CI(0.01, 0.94). No Group x Task interaction was found, $F(2.42,82.29) = 1.67$, $p = .19$, $\eta_p^2 = .05$, GGC.

3.2.3.1.3 Sensitivity and response bias

Higher FAs for ASD individuals indicate difficulties in distinguishing between old and new items. Therefore, the data were analysed in more detail by calculating measures of response criteria (Gaetano et al., 2015). Similarly to Experiment 1 (Section 2.1.3.1.3), A' (Pollack & Norman, 1964) was calculated as a measure of sensitivity, and B" (Grier, 1971) was used as a measure of response bias. The data are presented in Table 3.13.

Table 3.13

Means and Standard Deviations for A' (sensitivity) and B" (response bias) for recognition responses for the four tasks for ASD and TD groups in Experiment 3.

	ASD		TD		Total	
	A'	**B"**	**A'**	**B"**	**A'**	**B"**
Task	*M (SD)*	*M (SD)*	*M (SD)*	*M (SD)*	*M (SD)*	*M (SD)*
Item	0.71 (0.14)	0.09 (0.28)	0.82 (0.17)	0.43 (0.43)	0.76 (0.17)	0.26 (0.39)
Location	0.61 (0.17)	0.06 (0.21)	0.81 (0.12)	0.35 (0.32)	0.71 (0.17)	0.21 (0.30)
Order	0.58 (0.20)	0.07 (0.27)	0.73 (0.22)	0.27 (0.29)	0.65 (0.22)	0.17 (0.29)
Associative	0.54 (0.15)	-0.01 (0.17)	0.67 (0.20)	0.12 (0.31)	0.60 (0.19)	0.06 (0.25)

For A' data, a significant main effect of *Group*, $F(1,34) = 11.74$, $p < .01$, Cohen's $d = 1.14$, 95 % CI(0.41, 1.82), with higher A' rates for the TD compared to the ASD group, indicated lower sensitivity and, therefore, more difficulty to distinguish between repeated and manipulated trials for the ASD compared to the TD participants. A significant main effect of *Task*, $F(3,102) = 8.64$, $p < .0001$, $\eta_p^2 = .20$, showed higher A' rates for *item* compared to *order*, $p < .05$, Cohen's $d = 0.58$, 95 % CI(0.10, 1.04), and *associative* tasks, $p < .0001$, Cohen's $d = 0.94$, 95 % CI(0.44, 1.41), and for *location* compared to the *associative* task, $p < .05$, Cohen's $d = 0.65$, 95 % CI(0.17, 1.12). There was no Group x Task interaction, $F(3,102) = 0.55$, $p = .65$, $\eta_p^2 = .02$.

Similarly, for B" data, a significant main effect of *Group*, $F(1,34) = 12.50$, $p < .01$, Cohen's $d = 1.18$, 95 % CI(0.45, 1.86), with higher B" rates for the TD compared to the ASD group, indicated a larger response bias to reject the correct answer for the TD compared to the ASD group. A significant main effect of *Task*, $F(3,102) = 4.64$, $p < .01$, $\eta_p^2 = .12$, showed higher B" rates for *item*, $p < .01$, Cohen's $d = 0.67$, 95 % CI(0.19, 1.14), and *location* tasks, p

$< .05$, Cohen's $d = 0.59$, 95 % CI(0.11, 1.05), compared to the *associative* task. The Group x

Task interaction was not significant, $F(3,102) = 1.36$, $p = .26$, $\eta_p^2 = .04$.

3.2.3.2 Correlations among tasks

Investigating the relations among tasks showed significant positive correlations between the

item task and each of the *relational* tasks as well as among all the *relational* tasks (see Table

3.14), indicating that better performance on one task was related to better performance on the

other tasks. However, separate analyses for the two groups indicated that these correlations

were mainly driven by the TD groups' performance. Despite the smaller sample size,

(marginally) significant correlations were found among all *relational* tasks and between the

item and all *relational* tasks for the TD group. By contrast, there were only two (marginally)

significant correlations among relational tasks and no significant correlations between the

item and the *relational* tasks for the ASD group.

Table 3.14

Bivariate correlations among corrected recognition rates for all four tasks of Experiment 3 for
both groups separately and in total.

	ASD			TD			Total		
Task	**loc**	**ord**	**asso**	**loc**	**ord**	**asso**	**loc**	**ord**	**asso**
ord	.44⁺			.75**			.70**		
asso	.01	.56*		.45⁺	.48*		.42*	.58**	
item	.14	.20	.13	.68**	.60**	.55*	.57**	.55**	.50**

Note. item = item test. loc = location test. ord = order test. asso = associative test. $^+p < .1$.

*significant at $p < .05$. **significant at $p \le .01$.

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3.2.3.3 Exploratory regression analyses regarding the effects of age

Bivariate correlations to investigate the effect of age on memory performance (i.e., corrected recognition; see Table 3.15) showed that age was significantly negatively correlated with corrected recognition in the *order* task for both groups in total and for the TD group separately, indicating lower order task performance with increasing age. No other significant correlations were found for any of the other tasks in either group.

Table 3.15

Bivariate correlations between age and corrected recognition scores for all four tasks of Experiment 3 for both groups separately and in total.

	ASD				TD				Total			
	item	**loc**	**ord**	**asso**	**item**	**loc**	**ord**	**asso**	**item**	**loc**	**ord**	**asso**
age	.33	-.16	-.07	-.09	-.36	-.22	-.59*	-.12	-.07	-.15	-.34*	-.09

Note. item = item test. loc = location test. ord = order test. asso = associative test.
*significant at *p* < .05.

A regression analysis was then used to investigate how much variance in memory performance was explained by age. Age did not significantly explain variance in corrected recognition for the *item*, $R^2 = .00$, $F(1,34) = 0.15$, $p = .71$, *location*, $R^2 = .02$, $F(1,34) = 0.76$, $p = .39$, or the *associative* tasks, $R^2 = .01$, $F(1,34) = 0.27$, $p = .61$, for both groups in total. By contrast, age significantly explained 11.2 % of the variance, $R^2 = .11$, $F(1,34) = 4.31$, $p = .046$, and it significantly predicted corrected recognition rates in the *order* task, $\beta = -.34$, 95 % CI(-0.02, 0.00), $p < .05$, for both groups in total.

Closer inspection of the data showed that this effect only held for the TD group. Age did not significantly explain any variance in corrected recognition in the *order* task for the ASD group, $R^2 = .01$, $F(1,16) = 0.09$, $p = .77$, but it significantly explained 34.6 % of the variance in corrected *order* recognition for the TD group, $R^2 = .35$, $F(1,16) = 8.47$, $p = .01$. Age significantly predicted performance in the *order* task for the TD group, $\beta = -.59$, 95 % CI(-0.03, -0.00), $p = .01$, (see Figure 3.13 for illustration).
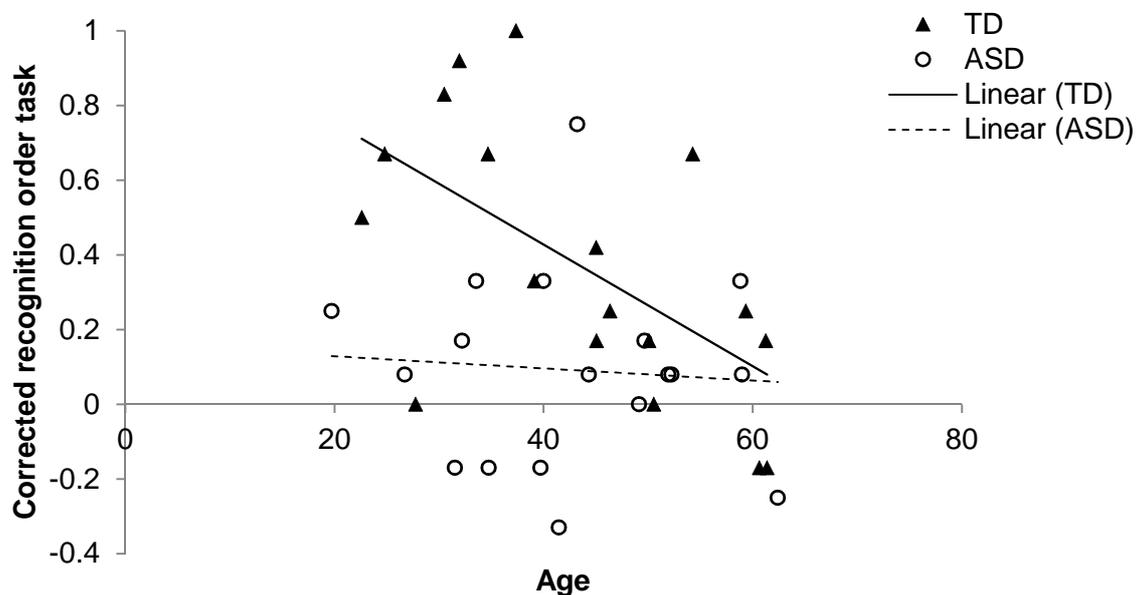
Figure 3.13. The relationship between age and corrected recognition rates for the order task of Experiment 3 with age explaining significantly more variance in order memory for TD compared to ASD participants.

Re-running the analysis for both groups in total including Age and a Group x Age interaction term showed that age explained significantly more variance in order memory among TD compared to ASD individuals. Using the forward method, the best model included Age and Group x Age interaction, which significantly explained 22.7 % of the total variance in

corrected recognition for the *order* task, $R^2 = .23$, $F(2,33) = 4.84$, $p < .05$. Age, $\beta = -.35$, 95 % CI(-0.02, -0.00), $p < .05$, and Group x Age interaction, $\beta = -.34$, 95 % CI(-0.01, 0.00), $p < .05$, significantly predicted performance in the order task for both groups in total.

3.2.4 Discussion

The aim of this study was to compare, directly, item with relational memory for temporal order, location, and inter-item associations using tasks that have the same relational processing requirements. Novel abstract shape images were used to control for the influence of language and previous experiences with the materials on memory. Preliminary analyses were run to investigate the effect of age on relational memory in both groups.

In the task, participants studied black shape triplets that were presented in sequential order in three different screen locations. At test, items or relations were either unchanged (as seen at study), or they were manipulated. It was predicted that, in line with the relational binding account (Bowler et al., 2011), ASD individuals would show particular difficulties in the relational memory tasks. The large age-range of the recruited sample allowed the exploratory investigation of the effects of age on relational memory in both groups, which was of interest because of a lack of research in this area, because of the known changes in relational memory processes with age over the typical lifespan (Naveh-Benjamin, 2000), and because even younger adults with ASD have been found to show a similar memory profile to healthy TD OA (see Bowler, 2007).

The first prediction was not supported by the data. Although, ASD compared to TD individuals showed significantly lower performance in the three *relational* memory tasks, replicating and extending earlier reports of difficulties with memory for spatial relations (Bowler et al., 2004; 2014; Cooper et al., 2015; Semino et al., in preparation; Experiment 2),

and serial order in ASD (Bowler et al., 2016; Bennetto et al., 1996; Poirier et al., 2011; Gaigg et al., 2014), persons with ASD also showed difficulties with the *item* memory task. Similarly to Experiment 1, difficulties in ASD were related to distinguishing between old and new items, which became apparent in higher FA rates and lower sensitivity in their responses. Unlike the current finding, difficulties in item memory in ASD had not been found in Experiment 2 of this thesis, and there are some possible explanations for these inconsistencies.

One possibility is that some *item* memory tests inadvertently probe *relational* memory in that participants are encouraged to encode relations between items and their context. This process may then benefit subsequent context memory as well as memory for the items *per se*. This suggestion is supported by the high positive correlations between performance on *item* and *relational* memory tasks in the TD group in the current study, suggesting that TD individuals may have drawn on relational processing in the item task even though they had not been asked to do so, and the task would have been solvable without. Further support for the idea that relational processing is probed by some item memory tasks comes from Experiment 1 of this thesis, showing that recognition memory was compromised in ASD primarily in terms of Remembering (i.e., retrieving item and context information), but not Knowing, and a recent imaging study in ASD confirmed that Remembering relies much more on relational processing at encoding than Knowing (Gaigg et al., 2015). A lack of significant positive correlations between item and relational memory task performance for ASD individuals in the current study suggested that they did not engage in such spontaneous relational processing, as has been shown previously (e.g., in Gaigg et al., 2008), and did, therefore, not rely on relational information to support item test performance. Future studies should address this possibility by combining the paradigm employed here with a

manipulation of encoding instructions that would either foster or interfere with relational encoding. Conditions that interfere with relational processing during encoding should lead to equivalent performance on item tests for ASD and TD participants, whereas conditions that either allow for or encourage relational processing at study, should lead to similar group differences on item tests as observed here.

Another issue relating to inconsistencies found in item memory task performance in ASD concerns the concepts of 'complexity' and 'relational processing', and how these may map on to one another. A strong point of the paradigm developed by Konkel et al. (2008) is that the procedures for the different test conditions are nearly identical and, therefore, are closely matched on complexity, whilst manipulating the need for relational processing. To solve the task, participants need to form at least two binary relations (e.g., between two items or between an item and a location or serial position). Forming three binary or one ternary relation, however, would build more confidence for a correct answer. ASD participants may have difficulties with forming binary (found in Experiment 2) and, particularly, ternary relations (Bowler et al., 2011), which may explain the difficulties observed in the current study. Halford's (1992) taxonomy of cognitive development (see Section 1.4.1.4) with the different types of relations may be a good operationalization of task complexity and may help to unify explanations for the memory profile in ASD that are framed in terms of 'complexity' (Minshew & Goldstein, 1998) with those with reference to the distinction between item and relational memory (Bowler et al., 2011).

A comparison between the different relational memory tasks was complicated by the difficulty level of the tasks for participants. It is not possible to completely rule out that task difficulty may have masked disproportionate difficulties on relational compared to item tasks, or on one relational compared to the other relational tasks. However, effect sizes were large

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for the between-group differences on all tasks, and confidence intervals for the effect sizes were overlapping (see Figure 3.12), suggesting that all three tested relations were similarly difficult for ASD individuals. This is in line with previous research finding similar difficulties comparing different relations in ASD (Bowler et al., 2004, 2014), and with Konkel and Cohen (2009) suggesting that all relations rely to the same extent on the same brain region, namely the hippocampus. So if ASD individuals show atypical hippocampal functioning (Section 1.4.2.1), there should not be a difference among memory for different kinds of relations. Comparing the current data to the findings of Konkel et al. (2008) supports ideas about hippocampal rather than wider MTL abnormalities in ASD, since ASD individuals' performance was more similar to that of the hippocampal patients, performing above chance on the item task only. These results are in line with a large body of literature (see Eichenbaum, 2004; Eichenbaum et al., 2007; A. Mayes, Montaldi & Migo, 2007 for reviews), suggesting that the hippocampus is critical for relational but not item-specific memory processes, whereas the wider MTL, including cortical areas surrounding the hippocampus (particularly the parahippocampal and perirhinal cortices), additionally support item memory. It is, however, worth noting that the ASD individuals' performance was better than that of Konkel et al.'s (2008) hippocampal patients, highlighting the need to consider other brain regions in addition to the hippocampus that may be involved in the emergence of memory difficulties in ASD. To this end, it is worth considering the correlations among the performance on the different tasks in more detail. Significant positive correlations among all tasks in the TD group seem to suggest that they recruited domain-general relational strategies flexibly in all conditions, whereas the absence of correlations among task performance in the ASD group suggests that they seemed to tackle each condition differently with less adaptive strategies. One reason may have been difficulties with flexibly using relational processes in

ASD, which may be related to hippocampal dysfunction, since hippocampal damage has been related to inflexible cognition and behaviour (Duff & Brown-Schmidt, 2012; Rubin, Watson, Duff & Cohen, 2014). Another possibility is that this inflexibility in ASD may indicate a difficulty with executive functions (i.e., flexible adaptation to the varying task demands) and, therefore, processes guided by the PFC. This possibility will be tackled in the next experiment.

Considering the exploratory investigation of the influence of age on relational memory, the findings for *order* memory were in line with Bowler's (2007) ageing analogy in that ASD individuals performed similarly to older TD participants in the current sample. Younger TD individuals had an advantage for relational memory processes over ASD individuals. This advantage, however, seemed to decrease as relational processing decreased in the course of typical ageing, resulting in smaller differences between the older groups. Similarly to the findings reported here and in Experiment 1, Lever and Geurts (2016) recently reported reduced age-related differences in visual memory in large ASD compared to TD samples, which also supported the *safeguard hypothesis* (Geurts & Vissers, 2012). The findings were, however, not in line with the stronger effect of age on ASD memory for location reported in Experiment 2. It is possible, that in Experiment 2 effects of age on memory in the TD group were obscured by a ceiling effect. More research is, therefore, needed to disentangle the effects of age on memory in ASD. More generally, it seems possible that factors underlying memory decline in TD OA may operate at an earlier age in ASD individuals, which may explain relational memory difficulties reported here and elsewhere (see Section 1.4.1), or they may follow a different developmental trajectory altogether. It is debateable why no effects of age were found in location and associative

memory in the current study, perhaps these would become apparent with larger samples and more variability in the data.

In conclusion, the present study supports and extends existing findings of relational memory difficulties in ASD to previously untested relations and suggests that age may have less influence on order memory in ASD compared to TD individuals. By showing difficulties in item memory in ASD, the current study questions to what extent and under what circumstances item memory may be intact in ASD, and whether TD and ASD individuals similarly rely on item information when processing relations and vice versa. A further question is whether ASD individuals are able to use relational processing, but prefer not to do so, or whether they use item processing as a compensatory mechanism. A comparison with Konkel et al. (2008) suggests better performance in ASD participants tested here compared to hippocampal patients, questioning a hippocampal theory of autistic memory and asking for the search of additional factors that may hinder or support autistic memory depending on brain regions outside the hippocampus. An example would be EFs that support the search for an appropriate strategy for a task and that are also involved in memory decline in TD OA. Paralleling memory performance in ASD and TD OA prompts further consideration of EFs in researching memory in ASD. This will be done in the next experiment. In addition, following the findings of Experiments 2 and 3 of difficulties with location information in ASD, the next study will address memory for spatial information. Finally, the next experiment will further investigate what role item memory may play in the context of relational memory in ASD, a question that was not answered completely by Experiment 3.

4 Chapter 4: Spatial navigation

4.1 Experiment 4: Spatial navigation

4.1.1 Theoretical background

Spatial navigation is the capacity to navigate in one's environment. Research distinguishes between different types of spatial navigation. *Egocentric navigation* is the capacity to relate one's personal point of view to the locations of objects in space (Hartley, Trinkler & Burgess, 2004). Using *allocentric navigation*, one relates objects and locations in space to one another to form a view-point independent abstract cognitive map of the environment (Bohbot et al., 2004). Spatial navigation is closely related to the concept of relational memory in that an individual needs to relate objects and locations in the environment in order to successfully navigate to a desired location. The distinction between egocentric and allocentric navigation is useful in that it can help to quantify which type of relational processing ASD individuals struggle with. In addition, this distinction is also dissociable at a neural level with egocentric navigation regulated through the caudate nucleus (Bohbot et al., 2004), whereas allocentric navigation was impaired after MTL (Feigenbaum & Morris, 2004; Goodrich-Hunsaker, Livingstone, Skelton, & Hopkins, 2010) and right hippocampal lesions in humans (Bohbot et al., 2004), offering a test of theories suspecting the hippocampus as an area of difficulty in ASD (Section 1.4.2.1). Similar to other forms of relational memory, allocentric navigation is expected to pose particular difficulties for persons with ASD. Previous studies on spatial navigation in ASD show, however, mixed evidence (see Table 4.1 and below).

Table 4.1

Overview of studies investigating spatial navigation in ASD compared to TD individuals.

Participant characteristics		Materials	Measures	Results		Cohen's
ASD	TD			ASD	TD	d
M (SD)	M (SD)			M (SD)	M (SD)	
Prior & Hoffmann (1990)						
N	12 (9 m)	12 (9 m)	Milner Maze				
		12 (9 m)					
age	13.75 (10-17)[a,b]	13.75 (10-17)[a,b]	Find & remember correct path through array - bottom left to top right	Errors	180.2 (119.5)	65.9 (29.5)	1.31
		11.33 (8-16)[a,b]				63.2 (40.6)	1.31
PIQ[c]	88 (76-109)[a,b]	100 (85-112)[a,b]	Criterion: tree consecutive error-free trials	Time	19.1 (12.1)	8.9 (1.8)	1.09
		107 (97-120)[a,b]				7.8 (2.1)	1.23
				N of individuals reaching criterion	1	6	
						8	
Edgin & Pennington (2005)						
N	24[d]	34[d]	Morris Water Maze	% time in target quadrant	39 (10.7)	43 (12.5)	0.89
age	11.46 (2.3)	12.04 (2.5)	Find & remember location of hidden target in virtual pool				
BD[e]	12 (4.3)	12 (4.1)					
VA[f]	104 (20.2)	109 (13.0)					

Participant characteristics		Materials	Measures		Results		Cohen's
ASD M (SD)	**TD** M (SD)				**ASD** M (SD)	**TD** M (SD)	**d**
Ring, Gaigg, Altgassen, Barr & Bowler (in revision)							
N 26 (23 m)	26 (18 m)	Morris Water Maze					
age 38.81	42.12	Find & remember location of	% time in target qua-	A	28.87 (29.74)	34.46 (32.17)	0.18
(11.8)	(12.1)	hidden target in virtual pool	drant	E	37.57 (32.79)	36.93 (31.32)	0.02
VIQ[g] 109	111	Egocentric (E) - landmarks					
(16.6)	(16.3)	moved					
PIQ[g] 108	107	Allocentric (A) - participant					
(19.6)	(17.6)	moved					
Lind, Bowler & Raber (2014a)							
N 20 (16 m)	20 (15 m)	Memory island					
age 8.67	8.32	Find target items in 3-D	Time in target quadrant	V	0.91 (0.04)	0.89 (0.07)	0.35
(1.4)	(0.9)	island environment		H	0.79 (0.17)	0.85 (0.08)	0.45
VIQ[h] 104	107	Visible (V, targets are marked	Time to target	V	66.12 (13.94)	60.24 (7.52)	0.53
(13.5)	(5.3)	by flags)		H	87.33 (26.49)	68.15 (10.83)	0.95
PIQ[h] 105	110	Hidden trials (H, no flags)	Successful trials	V	0.99 (0.06)	1.00 (0.00)	0.24
(18.1)	(14.2)			H	0.86 (0.19)	0.96 (0.09)	0.67
			Velocity	V	7.07 (1.05)	7.51 (0.70)	0.49
				H	7.60 (1.00)	8.02 (0.68)	0.49
			Path length	V	443.65 (23.32)	438.72 (34.51)	0.17
				H	634.33 (167.05)	537.28 (79.26)	0.74
			Cumulative distance to	V	30989 (7933)	28349 (4186)	0.42
			target	H	46373 (20316)	33307 (7673)	0.85

Participant characteristics		Materials	Measures		Results		Cohen's
ASD	TD				ASD	TD	d
M (SD)	M (SD)				M (SD)	M (SD)	
Lind, Williams, Raber, Peel & Bowler (2013)							
N	27 (21 m)	28 (21 m)	Memory island				
age	34.64	33.02	Find target items in a 3-D	Time in target qua-	V	0.80 (0.19)	0.81 (0.21)	0.05
	(13.0)	(16.4)	island environment	drant	H	0.69 (0.21)	0.81 (0.19)	0.60
VIQ[h]	110	113	Visible (V, targets are marked	Time to target	V	88.01 (39.13)	68.85 (28.51)	0.56
	(15.2)	(12.2)	by flags)		H	105.40 (45.80)	77.11 (29.18)	0.74
PIQ[h]	111	114	Hidden trials (H, no flags)	Successful trials	V	0.84 (0.22)	0.91 (0.25)	0.30
	(16.3)	(12.6)			H	0.72 (0.24)	0.86 (0.21)	0.62
				Velocity	V	7.16 (1.00)	7.88 (0.68)	0.84
					H	7.94 (0.67)	8.48 (0.52)	0.90
				Path length	V	580.35 (280.62)	539.48 (257.57)	0.15
					H	808.62 (342.59)	640.65 (221.61)	0.58
Pellicano et al. (2011)							
N	20 (18 m)	20 (18 m)	Foraging game				
age	10.64	11.03	Search array to find hidden	% visits to side with	Bl1	45.50 (16.77)	61.50 (20.91)	0.84
	(1.4)	(2.0)	targets	most targets	Bl2	62.25 (17.43)	63.25 (25.30)	0.05
VA[i]	103	106	Two blocks, timed task	Optimality search path	Bl1	0.63 (0.11)	0.70 (0.07)	0.76
	(16.5)	(13.9)			Bl2	0.65 (0.12)	0.74 (0.07)	0.92
NVA[j]	36	36	One side of array had	Consistency search	Bl1	0.79 (0.08)	0.85 (0.08)	0.75
	(8.1)	(5.0)	80 % targets	path	Bl2	0.80 (0.08)	0.87 (0.08)	0.88
				N of revisits	Bl1	20.35 (23.68)	12.05 (12.00)	0.44
					Bl2	27.05 (29.70)	8.35 (8.56)	0.86

Participant characteristics		Materials	Measures		Results		Cohen's
ASD	TD				ASD	TD	d
M (SD)	M (SD)				M (SD)	M (SD)	
Caron, Mottron, Rainville & Chouinard (2004)							
N	16 (15 m)	16 (15 m)	Human-sized maze				
age	17.60 (6.3)	18.90 (5.7)	Five tasks	Route following - errors	low	1.00 (0.70)	1.10 (0.80)	0.13
					high	1.50 (1.00)	1.60 (1.31)	0.09
VIQ[g/k]	102 (21.2)	111 (10.4)	Guided route learning & route execution	Route following - time	low	39.30 (11.70)	42.70 (8.70)	0.33
					high	48.60 (15.40)	52.80 (12.20)	0.30
PIQ[g/k]	112 (12.9)	107 (12.1)	Route retracing end to start	Route retracing - errors	low	1.60 (1.40)	2.30 (1.60)	0.47
					high	2.20 (1.30)	2.70 (1.20)	0.40
				Route retracing - time	low	45.70 (13.90)	51.40 (10.60)	0.46
					high	52.50 (11.60)	60.40 (9.90)	0.73
			Point to start or end (degrees)	Absolute pointing error		26.30 (31.60)	15.30 (19.60)	0.42
			Route recall - cued (sheet with maze pattern)	% participants passing test, route drawing (cued recall)		73.30[b]	30.80[b]	
			or free (empty sheet)	time route drawing (free recall)		65.10[b]	97.60[b]	
			Study map & route execution	Route execution - errors		1.40 (1.40)	0.80 (1.20)	0.46
				Route execution - time		57.70 (40.10)	79.10 (21.90)	0.66

Note. [a]Range. [b]SD not reported. [d]Gender distribution not reported. [e]BD - Block design, Wechsler Intelligence Scale for Children (WISC-III).

Performance IQ/nonverbal ability (NVA) - Leiter International Performance Scale (LIPS)[c]; Wechsler Abbreviated Scale of Intelligence (WASI)[h];

Raven's Standard Progressive Matrices[j]; Wechsler Adult Intelligence Scale (WAIS)[g]; WISC[k]. Verbal IQ/Verbal Ability (VA) - Peabody Picture

Vocabulary Test (PPVT-III)[f]; WASI[h]; British Picture Vocabulary Scale (BPVS)[i]; WAIS[g]; WISC[k].

In a test of simple spatial memory, the Milner Maze, that required participants to find and remember the correct path through an array over 15 trials, ASD compared to TD children and adolescents, matched on CA or VMA, needed longer to complete the task, made more errors, and fewer reached criterion (Prior & Hoffman, 1990). However, significant between-group differences in PIQ, and floor effects in both groups, with only one ASD participant and just half the TD sample reaching criterion on the task, compromised the interpretation of the results.

Asking matched groups of ASD and TD children and adolescents to navigate in a virtual pool environment to find a hidden platform in a computer-based version of the Morris Water Maze, Edgin and Pennington (2005) found no significant differences between groups. Between-group differences may have been attenuated by the significantly higher number of women in the TD group, because women have been reported to perform worse at spatial navigation (Astur, Tropp, Sava, Constable & Markus, 2004). In addition, it is possible that ASD participants may have compensated for potential allocentric problems by using intact egocentric processing, which was not addressed in this study because the authors tested their participants only with a place learning condition, i.e., testing simple spatial memory that enabled the use of allocentric as well as egocentric processing (Burgess, 2006). Ring, Gaigg, Altgassen, Barr and Bowler (in revision) improved the design of this earlier study by systematically manipulating task demands on egocentric and allocentric processing within the same task. While in the egocentric condition landmark objects moved around the pool area, the participants moved around the pool area themselves in the allocentric condition. ASD as opposed to matched TD adults spent a significantly shorter percentage of time searching in the target quadrant of the pool area to find the platform only in the allocentric condition, suggesting a specific allocentric navigation deficit in ASD. Slightly more women included in the TD group suggested that the between-group difference may be larger. In addition, more

difficulties would be expected when using a 3-D or real-life navigation environment instead of an aerial view, which may have made the formation of an abstract map easier for participants.

Such a 3-D environment is the island navigation task, where participants were asked to find previously studied target objects that were marked by flags (visible egocentric trials), or that were hidden (i.e., no support in the form of flags marking the positions of the objects was provided, allocentric trials). ASD children (Lind et al., 2014a) and adults (Lind, Williams, Raber, Peel & Bowler, 2013) both showed disproportionate allocentric navigation difficulties compared to matched TD participants. However, the results of these studies may have been confounded by order effects in that egocentric trials were always presented first. In addition, egocentric and allocentric conditions were not matched on complexity in that the task support in egocentric trials (i.e., the presence of the flag) may have made them easier for ASD individuals (see Section 1.4.1.3). This interpretation seems, however, unlikely since ASD adults, despite showing particular difficulties in allocentric navigation related to the time spent in the target quadrant of the island, performed generally worse (i.e., on egocentric and allocentric trials) on most other measures taken, such as time needed to find the target or velocity (Lind et al., 2013). This study, therefore, suggested a rather general spatial navigation deficit independent of condition.

In the foraging game, a real-life navigation environment, matched groups of ASD and TD children were asked to find hidden targets by searching 16 locations on the floor of an actual room. Pellicano et al. (2011) found that ASD as opposed to TD children needed significantly longer to learn which side of the search area was more rewarding (i.e., included more targets), their search paths were longer, and they did not search all the necessary locations on the way to the target (less optimal search). In addition, ASD children returned more often to a previously searched location and their search strategies were different across

blocks of trials (less systematic search). These data indicated difficulty in finding rules for the task as well as employing the rules to increase task performance. The experiment, however, does not disentangle the contributions of allocentric and egocentric navigation.

In another real life search environment - a human-size maze - adolescents and adults with and without ASD did not differ when asked to perform a studied route (after walking the route or studying a map) from start to end, to retrace the route from end to start, when pointing in the directions of start or end, or when drawing the studied route either on an empty sheet of paper (free recall) or on one that showed a maze pattern (cued recall; Caron, Mottron, Rainville & Chouinard, 2004). The lack of landmarks or cues in the navigation environment, which people have been found to utilise for real life allocentric navigation, made this task a simple spatial memory test. In addition, even though the task assessed spatial navigation in great detail, the lack of data, statistics, and effect size measures presented in the paper make the results elusive.

Finally, Maras, Wimmer, Robinson and Bowler (2014) studied mental imagery in ASD, which has been suggested as an underlying mechanism of forming abstract map representations for allocentric navigation. The authors tested 21 ASD (18 men, $M_{CA} = 40$ years, $M_{VIQ} = 105$, $M_{PIQ} = 101$) and 20 matched TD adults (17 men, $M_{CA} = 44$ years, $M_{VIQ} = 108$, $M_{PIQ} = 105$) on an island task asking participants, after having studied a map of an island, to imagine the distance between objects presented on the map. Both groups took similarly long to perform the task with increasing time needed relative to increasing actual distance between objects. VIQ and verbal WM (derived from the WM index score of the WAIS) were highly correlated with scanning performance in ASD individuals, suggesting that they particularly relied on verbal strategies and capacities to solve this visual task, which is consistent with reported difficulties on spatial short-term (Bowler et al., 2016) and working memory tasks (D. M. Williams, Jarrold, Grainger & Lind, 2014). Generating a mental image

of a previously studied map appears to be intact in ASD, but it remains unclear from this study whether ASD participants would also be able to generate a map of an environment that they navigate.

In summary, previous navigation studies in ASD show difficulties when tasks have high demands on relational processing. Most previous studies did not disentangle the contributions of egocentric and allocentric processing to successful spatial navigation in ASD, nor did they systematically compare conditions. When conditions were compared, often the order of their presentation was not counterbalanced, introducing a potential confound. However, manipulating the presentation order of conditions raises questions to what extent ASD individuals are able to switch between different conditions and how EFs may be needed to do this (Moffat, Kennedy, Rodrigue & Raz, 2007). When looking at strategies used for navigation, one study showed that ASD children were less optimal and less systematic in their search (Pellicano et al., 2011), and another study showed that ASD adults depended on verbal strategies for their task performance (Maras et al., 2014). There are, however, no systematic investigations in ASD assessing their use of navigation strategies, such as egocentric and allocentric processing. In addition, intact item memory is necessary for successful allocentric navigation (Youngstrom & Strowbridge, 2012). However, no previous study in ASD has tested item memory in the context of spatial navigation.

Some of these points have been addressed in the literature on spatial navigation in TD OA. On a task systematically comparing egocentric and allocentric navigation using the same maze learning paradigm and randomising the trial presentation, TD OA have shown particular difficulties in allocentric trials, and these difficulties were related to a reduced use of allocentric navigation strategies (Wiener, de Condappa, Harris & Wolbers, 2013). In addition, two other recent studies found specific age-related deficits in navigating an

originally studied route from a different direction (allocentric navigation; Wiener, Kmecova & de Condappa, 2012), and problems in flexibly switching between different navigational strategies especially in switching from egocentric to allocentric trials (Harris, Wiener & Wolbers, 2012) in TD OA.

Based on the literature reviewed, the aims for the current study were the following. First, it was aimed to systematically compare egocentric and allocentric navigation using the same task placing similar relational processing requirements on participants in both conditions. Second, it was of interest to assess which type of navigation strategy (i.e., egocentric or allocentric) both groups of participants use for their task performance in allocentric trials, and how well they can switch between different navigation conditions. Third, it was aimed to measure EFs and item memory for landmarks presented during the spatial navigation task and their role for successful navigation. Forth, it was of interest to investigate the potential effects of age on egocentric and allocentric navigation in both groups. Following the results on the differences in the allocation of attention at encoding in ASD (Sections 3.1.1.1, 3.1.3.4.1), it was aimed to assess attention to landmarks at encoding in the context of spatial navigation through the measurement of eye movements. Finally, attention to landmarks at retrieval was of interest, and it was measured through eye movements.

Following these aims, a task was chosen that systematically compared egocentric and allocentric navigation relying on the same relational processing requirements. In particular, at study, participants were presented with a route through a maze including four four-way intersections. Each intersection was marked with two unique landmarks, which were presented in opposite corners of the intersection. At each intersection, the route either turned left or right. At test, participants were presented with static images of the intersections that were either presented as coming from the same direction as at study (measuring egocentric

navigation) or as coming from a different direction (measuring allocentric navigation) in randomised order. Participants were asked to indicate the direction they needed to travel to follow the original route they had studied at each intersection. Fixation durations and number of fixations on the two landmarks presented at each intersection were measured at encoding and retrieval, and tasks measuring memory for the landmarks after the navigation task, as well as a task measuring EFs were included to assess their role for spatial navigation.

To examine the first aim, accuracy scores for the chosen directions at the intersections were inspected. If ASD participants show particular difficulties in relating object and location information to one another in space to form an abstract map presentation, they will only show difficulties in the allocentric condition of the task. Following the second aim, it was examined which strategy participants used for allocentric trials. If ASD participants show particular difficulties related to allocentric navigation, they will show reduced use of allocentric and increased use of egocentric strategies compared to TD individuals. Aim 3 was assessed by inspecting performance on trials after a switch, i.e., an allocentric trial was presented after an egocentric trial, or vice versa. In addition, set shifting was assessed with a task measuring EFs, and participants were asked for their memory for landmarks. If ASD participants show difficulties in EFs, they will show reduced performance after a switch between trials, in particular, after switching from an egocentric to an allocentric navigation trial. In addition, they will show more perseverative errors on the EF task. If ASD participants show intact item memory, there will be no between-group differences in memory for the landmarks for navigation. Regarding the effect of age on spatial navigation, if ASD individuals' spatial navigation performance is similarly affected by age as that of TD individuals, persons with ASD will show effects of age on allocentric but not egocentric navigation. Following Aim 5, fixation durations and number of fixations on the two landmarks presented at each intersection at encoding were assessed. If ASD individuals show difficulties with relational

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processing, these will be apparent already at encoding in shorter and fewer fixations on the two landmarks compared to TD participants. Regarding the final aim, fixation durations and number of fixations on the landmarks presented at the intersections at retrieval were examined. If persons with ASD show difficulties with relational processing, they will show shorter and fewer fixations on the two landmarks of the intersections at retrieval. Finally, if fixation durations and number of fixations at retrieval reflect a real memory phenomenon, eye-movement data will correlate with behavioural navigation data.

4.1.2 Predictions

Based on the ageing analogy (Bowler, 2007), it was predicted that ASD participants would show particular difficulties with allocentric navigation and with switching from egocentric to allocentric trials. It was also expected, that ASD adults would demonstrate a natural bias to adopt egocentric navigation strategies. EFs, item memory, i.e., memory for the landmarks along the route, and attention, as measured through eye movements, were assessed for their role on spatial navigation. It was expected that persons with ASD would show difficulties in EFs but not in item memory compared to TD participants.

Similarly to Experiments 1 - 3, a large sample with a broad age-range was recruited to examine the effect of age on spatial navigation performance in ASD. Allocentric navigation was of particular interest since research on TD OA has shown particular age-related difficulties in allocentric navigation (e.g., Wiener et al., 2013). Possible outcomes were stronger (*double jeopardy* - Geurts & Vissers, 2012; Experiment 2), weaker (*safeguard hypothesis* - Geurts & Vissers, 2012; Lever & Geurts, 2016; Experiments 1 and 3), or similar (*parallel development* - Geurts & Vissers, 2012) effects of age on allocentric navigation in ASD and TD adults.

Finally, following the results of Experiment 2, it was expected that the ASD group would attend less to the two landmark animals as the relevant information on the screen during encoding. Between-group differences in attention to the landmarks at test were also expected, reflecting difficulties in relational processing in ASD.

4.1.3 Methods

4.1.3.1 Participants

4.1.3.1.1   Behavioural data

Wiener et al. (2013) included 24 younger and 24 older TD adults. In addition, based on the data for younger and older adults provided by J. M. Wiener (personal communication, September, 1, 2016), power calculation using G*Power (Faul et al., 2007) showed that to detect a significant Group x Condition interaction with an effect size of $f = 0.67$ and a statistical power of 0.90, a total sample size of 10 participants would be needed. To increase statistical power because of the heterogeneity of ASD samples, 37 ASD (30 men, $M_{age} =$ 42.61 years, age range: 26-64 years) and 31 TD adults (25 men, $M_{age} = 40.71$ years, age range: 21-64 years) were matched on gender, $X^2 = 0.00$, $p = .96$, CA, VIQ, PIQ, and FIQ, as measured by the WAIS-III[UK] (The Psychological Corporation, 2000). Groups differed significantly in their AQ scores (Baron-Cohen et al., 2001; see Table 4.2). Thirty-two ASD individuals completed the ADOS (Lord et al., 1989), with eight individuals scoring just below the total cut-off score. In all cases the ADOS observations, however, were consistent with difficulties in social-affective behaviours that are considered as the hallmark of ASD, and since all individuals had received a clinical diagnosis before testing, they were included in the study.

Table 4.2

Descriptive statistics for ASD and TD participants in Experiment 4.

| Measure | ASD (30m, 7f) | | TD (25m, 6f) | | | Cohen's | | |
	M	*SD*	*M*	*SD*	*t*(66)	*p*	*d*	CI
Age (years)	42.61	12.5	40.71	13.8	0.60	.55	0.14	-0.33, 0.62
VIQ[a]	111	16.1	115	14.2	0.92	.36	0.22	-0.26, 0.70
PIQ[b]	107	16.2	110	12.8	0.74	.46	0.18	-0.30, 0.66
FIQ[c]	110	16.2	114	13.7	0.87	.39	0.21	-0.27, 0.69
AQ[d]	33.51	6.7	13.58	5.6	13.22	.00	3.22	2.47, 3.90
ADOS-C[f]	2.77 (1-6)	1.4						
ADOS-RSI[g]	6.03 (1-13)	2.9						
ADOS-Total[h]	8.63 (3-17)	3.5						
ADOS-Im[i]	1.19 (0-2)	0.7						
ADOS-SB[j]	1.38 (0-5)	1.2						

Note. [a]Verbal IQ (WAIS-III[UK]). [b]Performance IQ (WAIS-III[UK]). [c]Full-scale IQ (WAIS-III[UK]). [d]AQ - Autism-Spectrum Quotient. [e]ADOS - Communication subscale. [f]ADOS - Reciprocal Social Interaction subscale. [g]ADOS Total score – Communication + Reciprocal Social Interaction. [h]ADOS - Imagination/Creativity subscale. [i]ADOS - Stereotyped Behaviours and Restricted Interests subscale. ADOS scores are presented with range in brackets.

Similarly to the other studies presented in this thesis, ASD individuals reporting comorbidities and/or use of psychotropic medication (32 % for the current study) remained in the sample (see Section 2.1.2.1). Most common comorbid disorders in the current study were depression (42 %), anxiety disorder (17 %), ADHD (17 %), and dyslexia (17 %). In addition, OCD (8 %) and schizophrenia (8 %) were reported. Further, 42 % of ASD individuals took antidepressants and 8 % used antipsychotic medication. ASD individuals with and without

comorbidities and medication use did not differ significantly in terms of gender, $X^2 = 0.06$, $p = .81$, CA, VIQ, PIQ, and FIQ, $t_{max} < 1.16$, $p_{min} > .25$, Cohen's $d_{max} < 0.41$, 95 % CI_{max}(-0.30, 1.09). Finally, analysing the data without ASD individuals that reported comorbidities and/or medication use left the results reported below unaffected.

4.1.3.1.2 Eye-movement data

Five older, $t = 2.50$, $p = .02$, Cohen's $d = 1.20$, 95 % CI(0.20, 2.16), ASD adults (three men, $M_{age} = 54.74$ years, age range: 27-64, $M_{VIQ} = 110$, $M_{PIQ} = 101$, $M_{FIQ} = 106$), who did not differ significantly from the rest of the sample in terms of gender, $X^2_{max} = 1.68$, $p_{min} = .20$, VIQ, PIQ, and FIQ, $t_{max} < 0.94$, $p_{min} > .35$, Cohen's $d_{max} < 0.46$, 95 % CI_{max}(-0.51, 1.39), and three TD adults (two men, $M_{age} = 32.97$ years, age range: 26-46, $M_{VIQ} = 111$, $M_{PIQ} = 100$, $M_{FIQ} = 107$), who were not significantly different from the remaining TD participants in terms of gender, $X^2_{max} = 0.42$, $p_{min} = .52$, CA, VIQ, PIQ, and FIQ, $t_{max} < 1.37$, $p_{min} > .18$, Cohen's $d_{max} < 0.84$, 95 % CI_{max}(-0.40, 2.01), were excluded from the eye-movement analyses because Tobii software indicated that their eye-movement data validity was below 70 % on more than three experimental blocks. The remaining 32 ASD (27 men, $M_{age} = 40.72$ years, age range: 26-64 years) and 28 TD (23 men, $M_{age} = 41.54$ years, age range: 21-64 years) individuals were still matched on gender, $X^2 = 0.05$, $p = .82$, CA, VIQ, PIQ, and FIQ, and they differed significantly in AQ scores (Baron-Cohen et al., 2001; see Table 4.3).

Table 4.3

Descriptive statistics for ASD and TD participants for whom eye-movement data were available in Experiment 4.

| Measure | ASD (27m, 5f) | | TD (23m, 5f) | | | | Cohen's | |
	M	*SD*	*M*	*SD*	*t*(58)	*p*	*d*	CI
Age (years)	40.72	11.1	41.54	14.0	0.25	.80	0.07	-0.44, 0.57
VIQ[a]	112	16.5	115	13.8	0.89	.38	0.23	-0.28, 0.74
PIQ[b]	108	16.1	111	12.6	0.72	.48	0.19	-0.33, 0.69
FIQ[c]	111	16.4	114	13.5	0.84	.40	0.22	-0.29, 0.72
AQ[d]	33.13	6.7	13.79	5.2	12.37	.00	3.20	2.40, 3.92
ADOS-C[e]	2.81 (1-6)	1.4						
ADOS-RSI[f]	5.86 (1-13)	2.9						
ADOS-Total[g]	8.46 (3-17)	3.5						
ADOS-Im[h]	1.22 (0-2)	0.7						
ADOS-SB[i]	1.39 (0-5)	1.3						

Note. [a]Verbal IQ (WAIS-III[UK]). [b]Performance IQ (WAIS-III[UK]). [c]Full-scale IQ (WAIS-III[UK]). [d]AQ - Autism-Spectrum Quotient. [e]ADOS - Communication subscale. [f]ADOS - Reciprocal Social Interaction subscale. [g]ADOS Total score - Communication + Reciprocal Social Interaction. [h]ADOS - Imagination/Creativity subscale. [i]ADOS - Stereotyped Behaviours and Restricted Interests subscale. ADOS scores are presented with range in brackets.

4.1.3.2 Materials

A virtual environment displaying a tunnel bounded by brown brick walls to the right and left and a grey floor and ceiling, that had been programmed in Vizard 3.0, was adapted from Wiener et al. (2013).
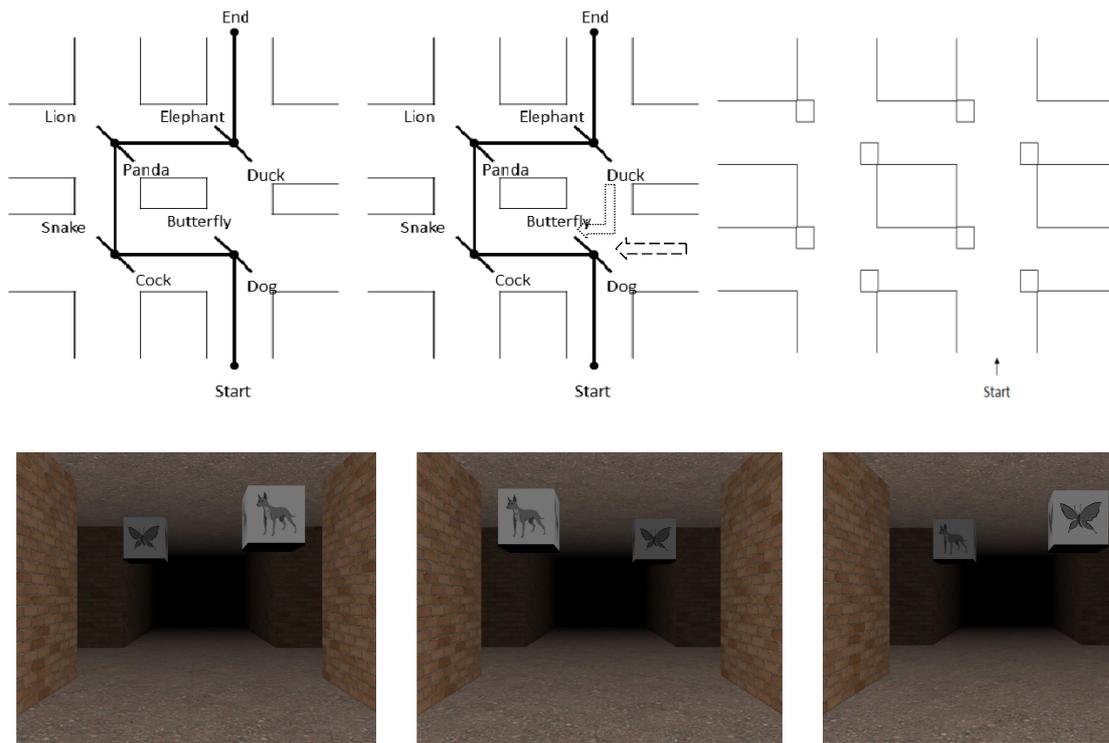
Figure 4.1. Images of the route through the maze used in Experiment 4. *Top left*: Schematic drawing of the route including the two landmark animals for each intersection. *Top middle*: Next to the route (black line), displaying the direction of same direction trials (egocentric), two arrows represent the directions of two different direction trials (allocentric) for the first intersection. *Top right*: Schematic drawing of an empty map used for cued recall tests of route and animals following the navigation test. *Bottom*: Examples of test images from the first intersection. *Bottom left*: Same direction (egocentric) test image; correct answer: turn left. *Bottom middle*: Different direction (allocentric) test trial coming from the right (dashed arrow in image top middle); correct answer: go straight on. *Bottom right*: Different direction (allocentric) test image coming from the opposite direction (dotted arrow in top middle image); correct answer: turn right.

In a 38-second video, participants were passively transported along a route through the environment turning either right or left at each of four four-way intersections, each marked with two pictures of animals (e.g., dog, snake, panda), serving as landmarks hanging from the ceiling of the maze in two opposite corners of the intersection (see Figure 4.1 top left for a

schematic drawing of the route). At test, participants were presented with 12 static images of the intersections in random order presenting them as coming from the same (four) or a different direction (eight) as at study. Same and different direction images differed in terms of the positions of the animal landmarks marking the intersections (see Figure 4.1 for examples). Different direction images never presented the intersection as coming from the direction in which the training route continued. Whereas same direction trials were used to measure egocentric navigation, different direction trials tested allocentric navigation.

4.1.3.3 Procedure

In a practice task, participants were presented twice with a video of a virtual route that turned either right or left at each of two four-way intersections at study. At test, they took part in one same and one different direction trial. After receiving corrective feedback and another practice in case of a wrong answer, as well as the chance to ask questions, the test proper started. The experiment was presented in Tobii studio Version 3.1.6, and a Tobii TX300 recorded eye movements during study and test with a sampling rate of 240 Hz. For this purpose, before each study and test phase participants were asked to complete a five-point calibration procedure, thus allowing them to readjust their seating position and to take breaks between blocks. Over the course of six study-test blocks, participants were asked to learn a new route through the maze, including four four-way intersections, with the route either turning right or left at each intersection. In every block, participants watched the same route video twice at study, followed by seeing the same 12 test trials - four same- and eight different-direction trials - in random order at test. Participants were told that the test trials represented the intersections they had seen in the route video, but that some of them were now presented as if approached from another direction, although never from the direction that would be opposite the direction of travel (i.e., participants knew that they would never have to make a U-turn). Participants were then asked to indicate the direction they would need to

travel to follow the original route they had studied. Answer possibilities were left, right, or straight on. The test images remained on the screen until participants gave a verbal response after which the next trial started. No feedback was provided at test.

After the last test block, participants' memory of the landmark animals marking the intersections and the route was tested. In a free recall test, participants were asked to name all the animals they remembered and the experimenter noted down their answers. Participants were then presented with an empty map (see Figure 4.1 top right) displaying the four four-way intersections along with two empty boxes at each intersection to indicate the positions of the animal landmarks. The starting point of the route was indicated by an arrow pointing in the direction of travel, and participants were instructed to draw in the route they had studied, and to label the boxes with the names of the animals as far as they remembered them.

To measure the extent to which possible inflexible responses on the navigation task may be related to difficulties with EFs, cognitive flexibility was tested using the Intradimensional/Extradimensional shift task (*IED*) from the CANTAB. This task presented participants with pairs of pink shapes and white lines on top and measured rule learning based on reward and rule changes. Participants' response perseveration at Stage 8, presenting the extradimensional shift, i.e., a shift in reward from the pink shapes to the white lines, was of particular interest. The number of times participants continued to choose the pink shapes over the white lines because they had previously been correct and rewarded (perseverative mistakes) was measured. The IED has been shown to be sensitive to frontal lobe damage (Owen et al., 1993), and ASD individuals were reported to show more perseverative errors on the extradimensional shift of the task (Hughes, Russell & Robbins, 1994; Ozonoff et al., 2004), making the IED a good control task.

4.1.3.4 Scoring

4.1.3.4.1 Behavioural data

First, participant's responses were scored as a percentage of correct trials for each block to obtain an *accuracy score*. Using the same data, *switch costs* were calculated as a percentage of correct trials following a switch between egocentric and allocentric trials. The data were averaged across the six test blocks, because not every switch type occurred in every block, because of the randomised trial presentation. An *allocentric switch*, where a same direction trial (egocentric) was followed by a different direction trial (allocentric), was distinguished from an *egocentric switch*, where a different direction trial (allocentric) was followed by a same direction trial (egocentric). Finally, *strategy scores* were derived from the two different direction trials, where the three different directions represented the three strategies. Scores were calculated as the percentage of times participants gave an answer according to each of the three strategies, as explained in reference to Figure 4.2.
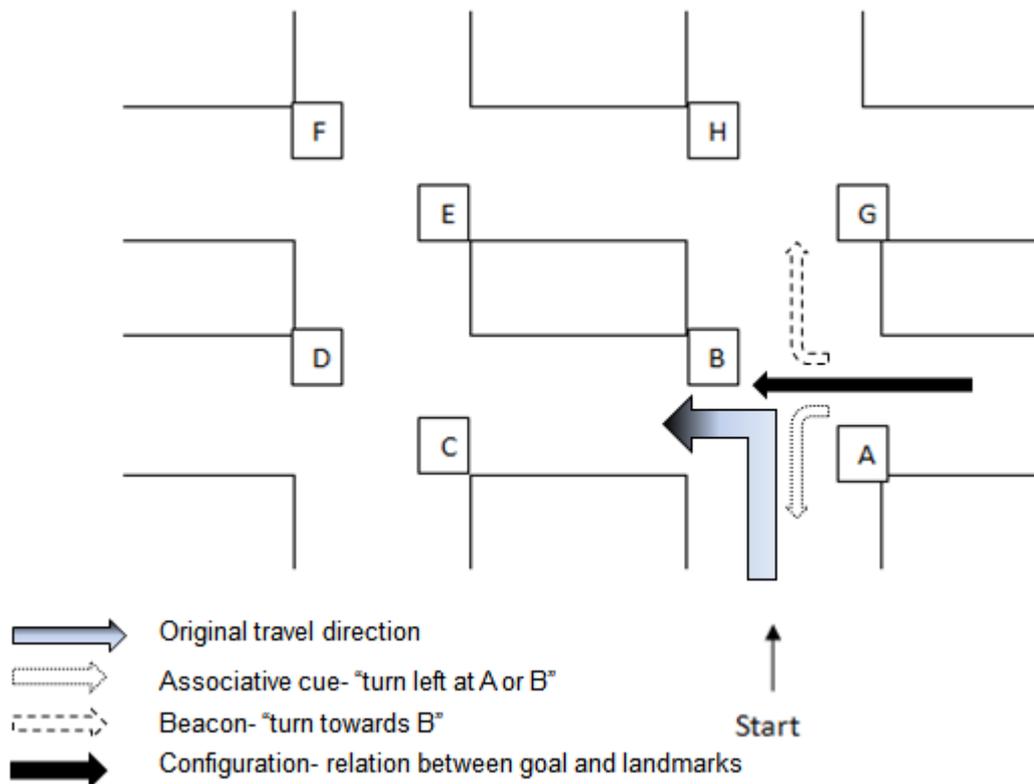
Figure 4.2. Schematic drawing to display the three different strategies for a different direction (allocentric) trial that distinguished between all three strategies and the directions that followed these strategies in Experiment 4.

In the figure, the first intersection is marked by Landmark A in the bottom right-hand corner and Landmark B in the top-left hand corner, when approached from the original travel direction (grey arrow) in same direction trials coming from the bottom. The route turned left at this intersection at study, and to turn left would be the correct response at test for same direction trials. In the different direction trial presented at test, the same intersection is now approached from the right (black arrow) and is marked with Landmark A in the bottom left-hand corner and Landmark B in the top right-hand corner (see Figure 4.1 bottom middle for the actual image). Using a *Configuration strategy*, the participant would have encoded the original relationship between the two landmarks and the travel direction, and would give the correct answer to go straight at this intersection, following the original travel direction. If a

participant used only one of the landmarks as a cue, for example, they remembered to turn left at Landmark A or B, the answer would be to turn left (dotted arrow), leading to an incorrect answer and a score for the *Associative Cue strategy*. A third possibility is that the participant used one of the landmarks as a beacon, making them turn away from Landmark A or turn towards Landmark B, resulting in a right turn (dashed arrow), an incorrect answer, and a score for the *Beacon strategy*.

4.1.3.4.2   Eye-movement data

Total duration and number of fixations on the front animal (ROI1) and the landmark animal presented at the back of the intersection (ROI2) were extracted using Tobii studio Version 3.3.0. Fixations were defined as lasting a minimum of 100 ms. Eye movements were recorded at study, i.e., while participants watched the route video, and at test, i.e., while participants viewed same (egocentric) and different (allocentric) direction test images. Eye movements at study (encoding) were averaged across the two video presentations of each trial, and were analysed separately for the six blocks of the task to investigate changes in eye movements across the duration of the task. Similarly, eye movements at test (retrieval) were calculated separately for the six blocks of the task, and for egocentric and allocentric test trials, to investigate changes in eye movements across the duration of the task as well as potential differences in eye movements between conditions.

4.1.4 Results

The data were analysed with Chi-Squared tests for nominal data, bivariate correlations, linear regression analyses, independent samples t-tests, and repeated measures ANOVAs. GGC was used, when the Sphericity assumption was violated, and Bonferroni corrected post hoc tests

were applied in case of significant differences. The level of significance was set to .05 and Cohen's *d* and partial Eta-Squared are reported as effect size measures.

4.1.4.1 Behavioural data

4.1.4.1.1 Accuracy

The data, presented in Figure 4.3, were analysed with a 2 (Group [ASD, TD]) x 2 (Trial type [egocentric, allocentric]) x 6 (Block [1, 2, 3, 4, 5, 6]) repeated measures ANOVA. A significant main effect of *Group*, $F(1,66) = 5.35$, $p < .05$, Cohen's $d = 0.56$, 95 % CI(0.07, 1.04), indicated higher accuracy for the TD ($M = 0.71$, $SD = 0.16$) compared to the ASD group ($M = 0.62$, $SD = 0.16$). Significant main effects of *Trial type*, $F(1,66) = 136.55$, $p < .0001$, Cohen's $d = 1.49$, 95 % CI(1.11, 1.86), and *Block*, $F(3.53, 232.66) = 10.06$, $p < .0001$, $\eta_p^2 = .13$, GGC, showed higher accuracy for egocentric compared to allocentric trials, and a gradual increase in performance from Block 1 to Block 6. No interactions were significant, $F_{max} < 1.76$, $p_{min} > .14$, $\eta_{p\ max}^2 < .03$.
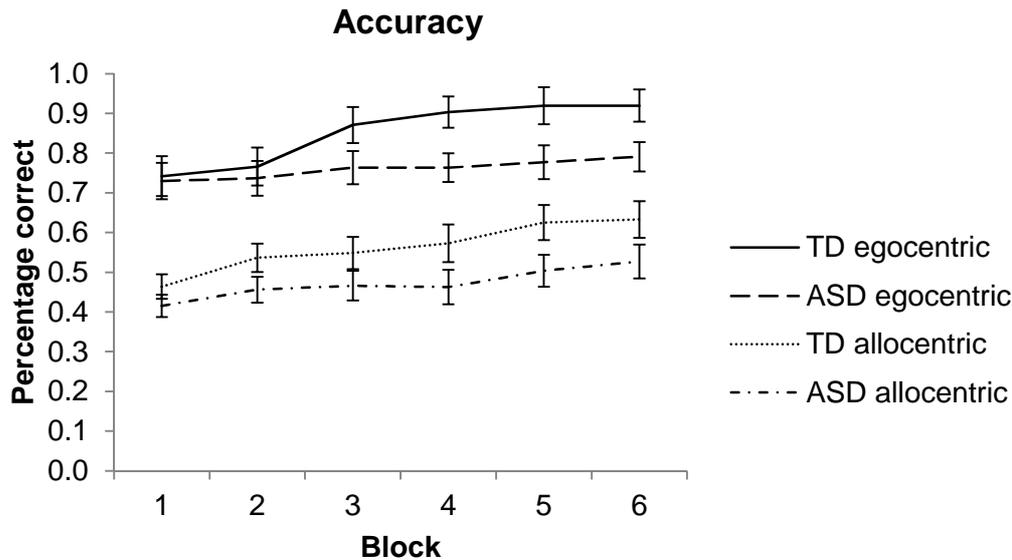
Accuracy

Figure 4.3. Accuracy in same (egocentric) and different direction (allocentric) trials across the six blocks of Experiment 4 for ASD and TD groups. The data are presented as mean $\pm$ SEM.

4.1.4.1.2 Allocentric vs. egocentric switch

A switch from an egocentric to an allocentric trial is called allocentric switch (EA), whereas a switch from an allocentric to an egocentric trial is named egocentric switch (AE). A 2 (Group [ASD, TD]) x 2 (Switch [EA, AE]) repeated measures ANOVA analysing switch data showed a marginal main effect of *Group*, $F(1,66) = 3.91$, $p = .05$, Cohen's $d = 0.48$, 95 % CI(-0.01, 0.96), with higher accuracy for the TD ($M = 0.70$, $SD = 0.22$) compared to the ASD group ($M = 0.62$, $SD = 0.26$), as well as a significant main effect of *Switch*, $F(1,66) = 79.11$, $p < .0001$, Cohen's $d = 1.26$, 95 % CI(0.88, 1.62), with higher accuracy for an allocentric to egocentric (AE; $M = 0.79$, $SD = 0.21$) compared to an egocentric to allocentric (EA; $M = 0.53$, $SD = 0.21$) switch. The interaction was not significant, $F(1,66) = 0.00$, $p = .98$, $\eta_p^2 = .00$.[14]

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[14] When analysing these data only including the 25 TD and 36 ASD individuals that also took part in the IED from the CANTAB, the direction of the effects stayed the same.

4.1.4.1.3 Strategy

Strategy scores are presented in Figure 4.4, and they were analysed with three separate 2 (Group [ASD, TD]) x 6 (Block [1, 2, 3, 4, 5, 6]) repeated measures ANOVAs. A non-significant trend for a *Group x Block* interaction, $F(5,330) = 1.91$, $p = .09$, $\eta_p^2 = .03$, was found for the *Associative Cue strategy*. No main effects were significant regarding the Associative Cue strategy, $F_{max} < 1.38$, $p_{min} > .24$, $\eta_{p\ max}^2 < .03$. Significant main effects of $Block_{Beacon}$, $F(4.24,279.61) = 6.68$, $p < .0001$, $\eta_p^2 = .09$, GGC, and $Block_{Configuration}$, $F(3.78,249.69) = 9.19$, $p < .0001$, $\eta_p^2 = .12$, GGC, however, showed a decrease in the use of the *Beacon strategy*, and an increase in the use of the *Configuration strategy* from Blocks 1 to 6. No other main effects or interactions were significant, $F_{max} < 1.46$, $p_{min} > .23$, $\eta_{p\ max}^2 < .03$.
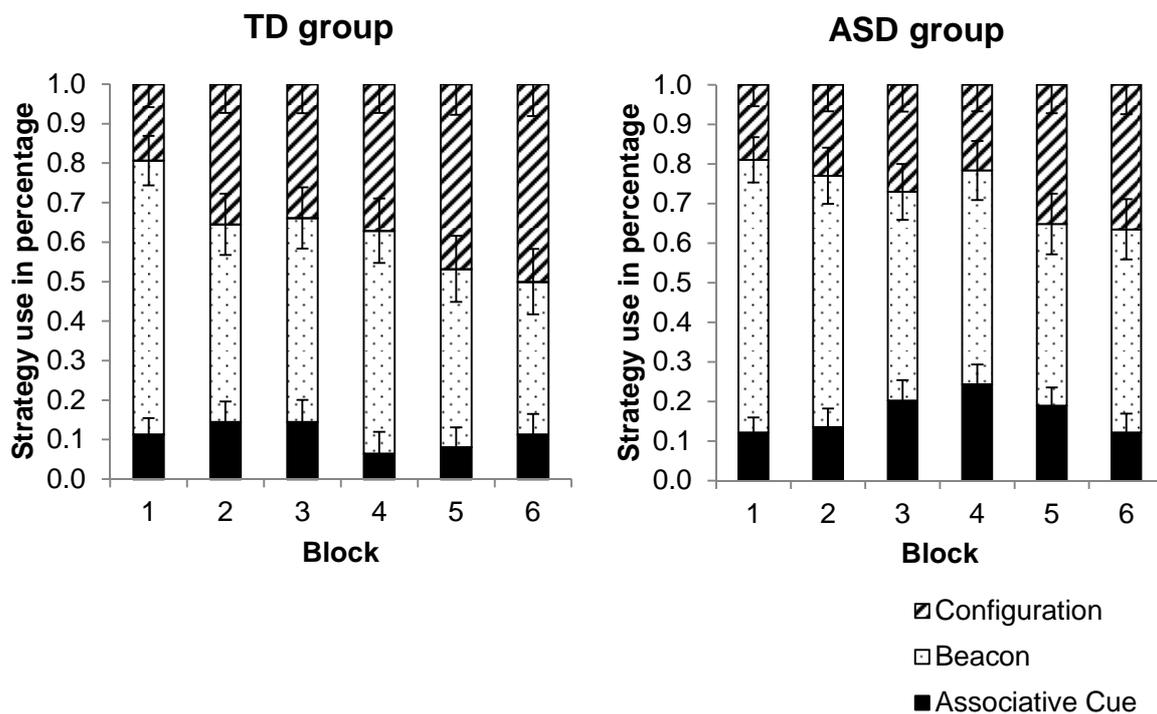
Figure 4.4. Strategy use in different direction (allocentric) trials that distinguished between associative cue, beacon, and configuration strategies for TD (left) and ASD (right) groups across the six blocks of Experiment 4. The data are presented as mean ± SEM.

4.1.4.2 Executive Functions

The data for the IED from the CANTAB were available for 36 ASD (29 men, M_{age} = 43.00 years, age range: 26-64 years) and 25 TD (21 men, M_{age} = 42.68 years, age range: 21-64 years) participants that were still matched in terms of gender, X^2 = 0.12, p = .73, CA, VIQ, PIQ, and FIQ, t_{max} < 0.33, p_{min} > .74, Cohen's d_{max} < 0.09, 95 % CI_{max}(-0.43, 0.59)[15]. ASD individuals (M_{ASD} = 11.67; SD_{ASD} = 11.1) showed significantly more perseverative errors at Stage 8 of the IED compared to the TD group (M_{TD} = 5.76; SD_{TD} = 7.1), t = 2.52, p = .01, Cohen's d = 0.61, 95 % CI(0.08, 1.12). Inspecting bivariate correlations to investigate the role of EFs on spatial navigation, significant negative correlations were found between perseverative errors on the IED and egocentric and allocentric navigation for the groups in total and for the TD group, indicating the more perseverative errors participants made, the worse their navigation performance (see Table 4.4).

Table 4.4

Bivariate correlations between navigation performance on egocentric and allocentric trials and perseverative errors on the IED of the CANTAB as a measure of executive functions, as well as memory for the landmark animals placed along the route for ASD and TD groups in Experiment 4.

	ASD Ego[a]	ASD Allo[b]	TD Ego[a]	TD Allo[b]	Total Ego[a]	Total Allo[b]
IED[c]	-.22	-.33	-.60**	-.42*	-.34**	-.38**
Free recall	.28	.32	-.09	.07	.23	.28*
Cued recall	.23	.28	-.00	.53**	.21	.41**

Note. [a]Accuracy for egocentric trials. [b]Accuracy for allocentric trials. [c]Perseverative errors at the extradimensional shift Stage 8 of the IED of the CANTAB. *significant at p < .05. **significant at p < .01.

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[15] When analysing the behavioural navigation data presented above for this reduced sample, the direction of the effects stayed the same.

When entering Perseverative errors and a Group x Perseverative errors interaction term into a multiple linear regression using the forward method to predict *allocentric navigation*, Perseverative errors remained as the only significant predictor, β = -.38, 95 % CI(-0.01, -0.00), $p < .05$, explaining 14.2 % of overall variance, R^2 = .14, $F(1,59)$ = 9.74, $p < .01$, in allocentric navigation. Similarly, Perseverative errors significantly predicted *egocentric navigation*, β = -.34, 95 % CI(-0.01, -0.00), $p < .05$, explaining 11.8 % of overall variance, R^2 = .12, $F(1,59)$ = 7.89, $p < .01$.

4.1.4.3   Free recall and cued recall

As is displayed in Table 4.5, the TD group recalled significantly more landmark animals than the ASD group in free, $t(66)$ = 2.70, $p < .01$, Cohen's d = 0.66, 95 % CI(0.16, 1.14), and cued recall tests, $t(66)$ = 2.33, $p < .05$, Cohen's d = 0.57, 95 % CI(0.07, 1.05). TD participants also recalled slightly better the animals' positions along the route, $t(65.99)$ = 1.97, p = .05, Cohen's d = 0.47, 95 % CI(-0.02, 0.95), compared to the ASD group. There were, however, no significant between-group differences in the recall of turns along the route, when participants were cued with the map, $t(66)$ = 0.98, p = .33, Cohen's d = 0.24, 95 % CI(-0.24, 0.72).

Bivariate correlations to investigate the role of item memory on navigation performance showed significant positive correlations between memory for animals and allocentric navigation (see Table 4.4), indicating the better participants remembered the animal landmarks, the better they performed on allocentric navigation trials. No significant correlations were found between item memory and egocentric navigation. When entering Free and Cued recall for animals as well as interaction terms of these variables and the Group factor into a multiple linear regression analysis using the forward method to predict *allocentric navigation* performance, Cued recall for animals remained as the only significant predictor, β = .41, 95 % CI(0.22, 0.76), $p < .0001$, explaining 16.9 % of total variance in

allocentric navigation performance, $R^2 = .17$, $F(1,66) = 13.43$, $p < .0001$. Item memory did not explain any variance in *egocentric navigation* performance.

Table 4.5

Means and Standard Deviations for free and cued recall item tests for the ASD and TD groups in Experiment 4.

	ASD (30m, 7f)	TD (25m, 6f)
	M (*SD*)	*M* (*SD*)
Free recall		
Animals (out of 8)	0.72 (0.18)	0.82 (0.14)
Cued recall		
Turns along the route (out of 4)	0.90 (0.25)	0.95 (0.19)
Animals (out of 8)	0.71 (0.18)	0.80 (0.13)
Animal positions (out of number of animals)	0.57 (0.39)	0.74 (0.32)

Finally, to consider EFs and item memory within the same model, Perseverative errors on the IED and Cued recall for animal landmarks were entered into a multiple linear regression using the forward method to predict allocentric navigation. The best model significantly explained 21.3 % of total variance in *allocentric navigation* performance, $R^2 = .21$, $F(2,58) = 7.84$, $p < .01$, and included Perseverative errors, $\beta = -.30$, 95 % CI(-0.01, -0.00), $p < .05$, as well as Cued recall for animals, $\beta = .28$, 95 % CI(0.04, 0.58), $p < .05$, as significant predictors for allocentric navigation (Figure 4.5). However, Perseverative errors remained as the only significant predictor for *egocentric navigation* (see Section 4.1.4.2).
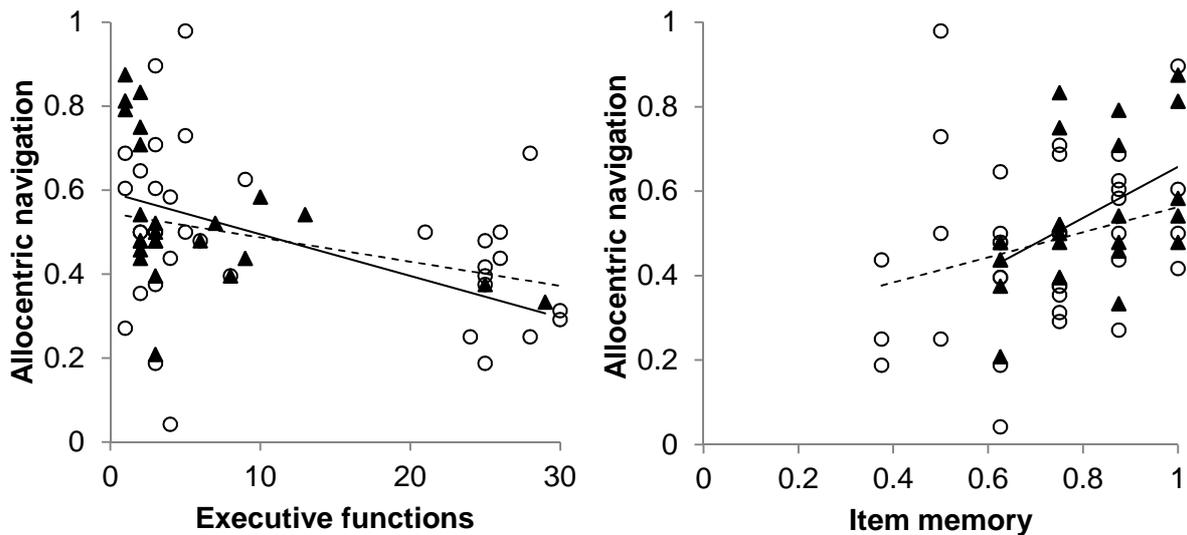
Figure 4.5. The relationship between perseverative errors on the IED of the CANTAB (EFs) and different direction (allocentric) navigation (left), and between cued recall for animal landmarks (item memory) and different direction (allocentric) navigation performance (right) in Experiment 4, with EFs and item memory significantly predicting allocentric navigation performance. Black triangles = TD. White circles = ASD. Solid line = linear regression line TD. Dashed line = linear regression line ASD.

4.1.4.4 Exploratory regression analyses regarding the effects of age

Similarly to Experiments 1 to 3, it was of interest to explore the effects of age on navigation performance because of the similarity between memory in TD OA and in ASD(ageing analogy; Bowler, 2007), and because of the known effects of age on allocentric navigation performance in healthy older TD individuals (e.g., Wiener et al., 2013). First, bivariate correlations were investigated, which showed no significant relations between navigation performance and age (see Table 4.6).

Table 4.6

Bivariate correlations between performance on egocentric (same direction) and allocentric (different direction) trials and age for the participants in Experiment 4.

	Egocentric	Allocentric
age	-.04	-.20[+]

Note. [+]$p < .1$. *significant at $p < .05$. **significant at $p \leq .01$.

Since it was still possible that age may have had a different effect on navigation performance in the two groups (Bewick et al., 2003), multiple linear regression analyses were run including Age and a Group x Age interaction term to predict navigation performance. The Group x Age interaction term explained 6.9 % of the variance, $R^2 = .07$, $F(1,66) = 4.89$, $p = .03$, and it significantly predicted *allocentric navigation* performance, $\beta = -.26$, 95 % CI(-0.00, 0.00), $p < .05$. Visual inspection of the right-hand panel of Figure 4.6, along with the inspection of the regression coefficients, showed that age was a better predictor of allocentric navigation performance in the TD as opposed to the ASD group. Similarly, the Group x Age interaction term explained 6.8 % of the variance, $R^2 = .07$, $F(1,66) = 4.79$, $p = .03$, and it significantly predicted *egocentric navigation* performance, $\beta = -.26$, 95 % CI(-0.00, 0.00), $p < .05$. Visual inspection of the left-hand panel of Figure 4.6 showed that age was a better predictor of egocentric navigation performance in the ASD as opposed to the TD group.
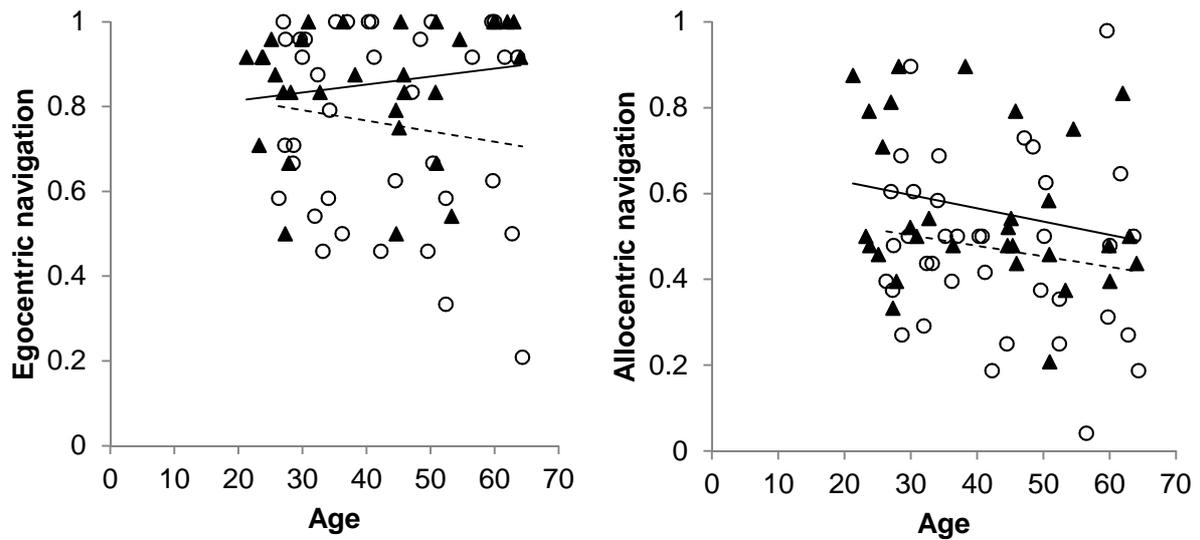
Figure 4.6. The relationship between age and egocentric navigation (same direction trials, left), and between age and allocentric navigation performance (different direction trials, right) in Experiment 4, with a stronger age-related difference in egocentric navigation in the ASD group and in allocentric navigation in the TD group. Black triangles = TD. White circles = ASD. Solid line = linear regression line TD. Dashed line = linear regression line ASD.

4.1.4.5 Eye-movement data

4.1.4.5.1 Encoding

Eye-movement data gathered while participants watched the route video at study are presented in Table 4.7, and they were analysed with 2 (Group [ASD, TD]) x 2 (ROI [ROI1, ROI2]) x 6 (Block [1, 2, 3, 4, 5, 6]) repeated measures ANOVAs.

Table 4.7

Total fixation durations and number of fixations during encoding on the front animal (ROI1)

and the animal presented at the back of the intersection (ROI2) across the six experimental

blocks of Experiment 4 for ASD and TD groups.

		ASD (27m, 5f)		TD (23m, 5f)	
		ROI1	ROI2	ROI1	ROI2
Measure		*M* (*SD*)	*M* (*SD*)	*M* (*SD*)	*M* (*SD*)
Total Fixation Duration in s					
Block	**1**	8.72 (3.80)	10.27 (4.91)	10.33 (2.67)	11.57 (3.59)
	2	8.42 (3.64)	9.79 (4.03)	10.17 (2.66)	10.55 (3.29)
	3	8.21 (3.37)	9.18 (4.05)	9.92 (2.93)	10.16 (3.06)
	4	7.91 (3.54)	8.70 (4.06)	10.60 (2.83)	10.78 (3.10)
	5	8.03 (4.04)	8.92 (4.25)	10.24 (3.38)	11.11 (3.76)
	6	8.66 (4.38)	8.58 (4.32)	9.77 (3.45)	10.69 (3.20)
Number of Fixations					
Block	**1**	29.13 (12.24)	33.78 (15.14)	33.68 (7.48)	37.79 (11.11)
	2	29.56 (9.92)	34.03 (13.08)	34.46 (7.04)	36.54 (15.56)
	3	29.41 (9.66)	32.75 (13.25)	35.00 (10.46)	36.71 (11.61)
	4	27.69 (9.82)	30.47 (13.01)	36.32 (9.17)	37.75 (12.99)
	5	27.91 (14.01)	31.13 (14.58)	33.89 (13.76)	39.54 (12.52)
	6	30.06 (14.92)	29.38 (14.53)	31.75 (9.42)	36.43 (11.05)

4.1.4.5.1.1 Fixations on objects

4.1.4.5.1.1.1 Total Fixation Duration

Significant main effects of *Group*, $F(1,58) = 5.90$, $p < .05$, Cohen's $d = 0.63$, 95 % CI(0.10, 1.14), and *ROI*, $F(1,58) = 4.92$, $p < .05$, Cohen's $d = 0.25$, 95 % CI(-0.11, 0.61), showed longer total fixations on the landmark animals for the TD compared to the ASD group, and shorter total fixations on the front (ROI1) compared to the back animal (ROI2). No interactions were significant, $F_{max} < 1.87$, $p_{min} > .10$, $\eta_p^2{}_{max} < .04$.

When running follow up tests to inspect if ASD compared to TD participants looked longer at the three different directions, no significant between-group differences were found, $F_{max} < 1.2$, $p_{min} > .33$, $\eta_p^2{}_{max} < .02$.

4.1.4.5.1.1.2 Number of Fixations

Similarly to the data on fixation durations, significant main effects of *Group*, $F(1,58) = 5.48$, $p < .05$, Cohen's $d = 0.61$, 95 % CI (0.08, 1.12), and *ROI*, $F(1,58) = 9.38$, $p < .01$, Cohen's $d = 0.32$, 95 % CI(-0.04, 0.68), showed more fixations on the landmark animals for the TD compared to the ASD group, and fewer fixations on the front (ROI1) compared to the back animal (ROI2). No main effect of Block or interactions were significant, $F_{max} < 1.35$, $p_{min} > .24$, $\eta_p^2{}_{max} < .03$.

4.1.4.5.2 Retrieval

The data are presented in Table 4.8, and they were analysed with 2 (Group [ASD, TD]) x 2 (Trial type [egocentric, allocentric]) x 2 (ROI [ROI1, ROI2]) x 6 (Block [1, 2, 3, 4, 5, 6]) repeated measures ANOVAs. ROI1 was specified as the animal presented in the front of the intersection at encoding, and ROI2 was the animal that had been presented at the back of the intersection at encoding.

Table 4.8

Total fixation duration and number of fixations during retrieval on the two landmarks presented at each intersection along the route - ROI1 (front animal at encoding) and ROI2 (back animal at encoding), across the six blocks of egocentric and allocentric trials of Experiment 4 for ASD and TD groups.

		ASD (27m, 5f)		TD (23m, 5f)	
		ROI1	ROI2	ROI1	ROI2
Measure		*M* (*SD*)	*M* (*SD*)	*M* (*SD*)	*M* (*SD*)
Total Fixation Duration in s					
Egocentric trials					
Block	**1**	2.40 (3.14)	1.98 (1.89)	1.71 (1.38)	1.78 (1.18)
	2	1.78 (2.38)	1.63 (1.38)	2.33 (1.91)	2.05 (1.15)
	3	1.57 (1.20)	1.45 (1.31)	2.37 (2.08)	2.21 (2.58)
	4	1.75 (2.11)	1.73 (2.08)	2.04 (1.77)	1.85 (1.04)
	5	1.43 (1.66)	1.54 (1.43)	2.04 (1.84)	1.74 (1.27)
	6	1.24 (1.13)	1.37 (1.16)	1.91 (1.57)	1.56 (0.91)
Allocentric trials					
Block	**1**	2.21 (1.87)	1.98 (1.61)	2.28 (1.34)	2.09 (1.09)
	2	1.92 (1.91)	1.67 (1.63)	2.64 (1.78)	2.49 (1.99)
	3	1.89 (1.75)	1.64 (1.56)	2.50 (1.97)	2.27 (2.00)
	4	1.62 (1.46)	1.46 (1.47)	2.51 (1.79)	2.08 (1.56)
	5	1.67 (1.08)	1.46 (0.97)	2.74 (2.42)	2.09 (1.46)
	6	1.82 (1.76)	1.47 (1.23)	2.33 (1.58)	1.99 (1.49)

		ASD (27m, 5f)		TD (23m, 5f)	
		ROI1	ROI2	ROI1	ROI2
Measure		*M (SD)*	*M (SD)*	*M (SD)*	*M (SD)*
Number of Fixations					
Egocentric trials					
Block	1	8.28 (7.99)	6.74 (5.38)	6.24 (4.77)	6.16 (4.11)
	2	6.46 (6.95)	6.03 (5.73)	8.44 (5.97)	7.16 (4.06)
	3	6.24 (5.22)	5.50 (5.82)	9.04 (7.51)	7.21 (6.12)
	4	7.02 (9.87)	6.47 (9.80)	7.40 (5.83)	6.20 (4.32)
	5	6.02 (9.37)	5.83 (6.63)	7.18 (6.00)	5.67 (4.25)
	6	4.78 (3.77)	4.88 (4.23)	7.15 (6.08)	5.18 (3.12)
Allocentric trials					
Block	1	7.81 (6.33)	7.52 (5.72)	8.05 (4.79)	7.42 (3.76)
	2	7.25 (8.98)	6.60 (6.49)	8.94 (5.93)	8.74 (6.08)
	3	6.40 (5.61)	6.05 (5.39)	8.23 (6.32)	8.07 (6.33)
	4	5.77 (6.68)	5.53 (5.21)	8.30 (6.60)	7.57 (5.34)
	5	6.04 (4.86)	5.67 (3.91)	8.81 (7.33)	7.09 (4.82)
	6	6.02 (5.76)	5.39 (4.23)	7.77 (5.52)	6.67 (4.22)

4.1.4.5.2.1 Egocentric vs. allocentric trials - Fixations on objects

4.1.4.5.2.1.1 Total Fixation Duration

A significant main effect of *Trial type*, $F(1,58) = 11.92$, $p < .01$, Cohen's $d = 0.17$, 95 % CI(-

0.19, 0.53), with longer total fixations in allocentric compared to egocentric trials was further

qualified by a significant *Group x Trial type* interaction, $F(1,58) = 5.04$, $p < .05$, $\eta_p^2 = .08$,

which showed that only TD participants fixated longer in allocentric as opposed to egocentric

trials, $p < .0001$, Cohen's $d = 0.28$, 95 % CI(-0.25, 0.81), whereas no difference between

conditions was found for the ASD group, $p = .38$, Cohen's $d = 0.06$, 95 % CI(-0.43, 0.55). By contrast with the encoding trials, a marginal main effect of *ROI*, $F(1,58) = 3.92$, $p = .05$, Cohen's $d = 0.16$, 95 % CI(-0.20, 0.52), showed longer total fixations on the front (ROI1) compared to the back animal (ROI2). A marginal *Group x Block* interaction, $F(2.99,173.50) = 2.52$, $p = .06$, $\eta_p^2 = .04$, GGC, was characterised by an increase in total fixation duration from Blocks 1 to 6 for the TD group, but a decrease for the ASD group. No other main effects or interactions were significant, $F_{max} < 1.89$, $p_{min} > .14$, $\eta_p^2{}_{max} < .04$.

4.1.4.5.2.1.2 Number of Fixations

A significant *Trial type* main effect, $F(1,58) = 9.28$, $p < .01$, Cohen's $d = 0.12$, 95 % CI(-0.24, 0.48), with more fixations for allocentric compared to egocentric trials, was again qualified by a significant *Group x Trial type* interaction, $F(1,58) = 5.23$, $p < .05$, $\eta_p^2 = .08$, showing that this was only the case for the TD group, $p < .01$, Cohen's $d = 0.21$, 95 % CI(-0.31, 0.74). The ASD group, however, showed similar numbers of fixations in egocentric and allocentric trials, $p = .58$, Cohen's $d = 0.03$, 95 % CI(-0.46, 0.52). Significant main effects of *ROI*, $F(1,58) = 5.65$, $p < .05$, Cohen's $d = 0.15$, 95 % CI(-0.21, 0.51), and *Block*, $F(3.21,185.93) = 2.69$, $p < .05$, $\eta_p^2 = .04$, GGC, showed more fixations on the front (ROI1) compared to the back animal (ROI2), as well as a decrease in the number of fixations from Blocks 1 to 6. No other main effects or interactions were significant, $F_{max} < 2.05$, $p_{min} > .10$, $\eta_p^2{}_{max} < .04$.

4.1.4.6 Correlations among behavioural and eye-movement data

4.1.4.6.1 Eye movements at encoding

To establish the extent to which fixations on the landmark animals at encoding may have contributed to later navigation performance[16], bivariate correlations were run between behavioural performance on egocentric and allocentric trials and difference scores of fixations on ROI2 and ROI1, since the analyses of encoding eye-movement data (see Section 4.1.4.5.1) had yielded that ROI2 had been fixated longer and more often at encoding as opposed to ROI1. Table 4.9 shows that there were no correlations between fixations on the landmark animals at encoding and subsequent navigation performance for the groups in total and the ASD group. Contrary to that, subsequent egocentric navigation in the TD group was significantly related to longer and more fixations on the back as opposed to the front object of the intersection at encoding.

Table 4.9

Bivariate correlations between fixation duration and number of fixations at encoding and subsequent navigation performance in Experiment 4.

	Ego ASD	Ego TD	Ego Total	Allo ASD	Allo TD	Allo Total
Fix dur ROI2 - ROI1[a]	-.27	.45*	-.03	-.25	-.02	-.15
N fix ROI2 - ROI1[a]	-.06	.43*	.15	-.19	-.03	-.09

Note. [a]Difference score of fixations on ROI2 (back animal of the intersection) and ROI1 (front animal of the intersection). *significant at *p* < .05. **significant at *p* < .01.

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[16] When analysing the behavioural data for the reduced sample of individuals for whom eye-movement data were available, the results were the same.

4.1.4.6.2 Eye movements at retrieval

To examine whether fixations on landmark animals at retrieval were related to navigation performance, bivariate correlations were run. Table 4.10 shows that allocentric navigation for the groups in total, as well as the ASD group, was significantly related to longer and more fixations on the animal that had been presented in the front as opposed to the animal that had been presented at the back of the intersection at encoding.

Table 4.10

Bivariate correlations between fixation duration and number of fixations at retrieval and navigation performance in Experiment 4.

	Ego ASD	Ego TD	Ego Total	Allo ASD	Allo TD	Allo Total
Fix dur ROI1 - ROI2[a]	.12	-.32	-.07	.38*	.25	.30*
N fix ROI1 - ROI2[a]	.07	-.29	-.08	.35*	.22	.28*

Note. [a]Difference score of fixations on ROI1 (front animal of the intersection at encoding) and ROI2 (back animal of the intersection at encoding). *significant at $p < .05$. **significant at $p < .01$.

4.1.5 Discussion

The aim of this study was to compare, systematically, allocentric and egocentric spatial navigation using a task that had the same relational processing requirements for both conditions. Item memory, EFs, and attention were measured to assess potential between-group differences and their influence on spatial navigation. Eye movements were also measured at retrieval to examine whether relational memory difficulties may be evident in

ASD in measures that operate outside awareness. Preliminary analyses were run to investigate the effect of age on navigation performance in both groups.

In the navigation task, participants studied a route through a maze crossing four four-way intersections, each marked with two unique landmarks presenting images of animals. At test, participants were presented with images of the intersections coming from the same (egocentric trials) or a different direction (allocentric trials) as at study. They were asked to indicate the original travel direction in every trial, which provided measures of accuracy, switch costs, and strategy. Item memory was tested by asking participants to recall the animals as well as the direction of the route using a map, and perseverative errors in the IED from the CANTAB served as a measure of EFs. Attention was assessed by measuring participants' eye movements.

Contrary to the prediction that ASD individuals would show particular difficulties with allocentric navigation, difficulties were observed in both same (egocentric) and different direction (allocentric) trials, supporting the finding of Lind et al. (2013) of a general navigation deficit in ASD independent of condition. In addition, unlike predictions of specific difficulties to switch to an allocentric strategy, ASD individuals showed general difficulties in switching between allocentric and egocentric trials. The lack of between-group differences in the use of the three strategies was against the third prediction of a reduced use of Configuration and an increased use of Beacon and/or Associative Cue strategies in ASD. This result is unlike Wiener et al. (2013), who had found a reduced use of the Configuration strategy in TD OA, possibly because of the dependence of this strategy on hippocampal functioning, which has been reported to decrease with age in TD individuals. It is possible that the fronto-hippocampal system is differently affected in ASD compared to TD OA. This suggestion is supported by looking at the effect of age on allocentric navigation performance in the current study, which was stronger for the TD compared to the ASD group. Similar

findings of the reduced effect of age on relational memory in ASD as opposed to TD individuals were also found in Experiments 1 and 3, supporting the *safe-guard hypothesis* (Geurts & Vissers, 2012; Lever & Geurts, 2016). Since allocentric navigation is dependent on hippocampal functioning (Bohbot et al., 2004), the reduced effect of age on allocentric navigation in ASD in the present experiment suggested that the hippocampus may be less affected in ASD, or that ASD individuals may have better compensatory mechanisms, which are not available for TD OA because of their age-related decline in other cognitive functions, such as frontal lobe functions. Maister et al. (2013) made a similar suggestion, when they found that only the ASD group with impairments in EFs also showed difficulties in memory in their sample. A stronger effect of age on egocentric navigation in ASD as opposed to TD individuals in the current study was, however, surprising. It may have been related to the fact that the current task relied heavily on cognitive flexibility in switching between different navigation strategies and, therefore, task performance was dependent on EFs. It may be that in tasks that place high demands on EFs, possible compensatory mechanisms relying on frontal lobe functioning, may not work well in ASD, because of a reliance on the same functions. Another possibility that may explain age-related effects on egocentric navigation is that in the current study a specific subgroup of persons with ASD may have participated that had particular difficulties with EFs, as indicated by the higher number of perseverative errors on the IED. Because of the demands on EFs in the task, difficulties may have already been apparent in egocentric navigation. In a more general context, it is important to note that the current study as well as Experiments 1 - 3 used a cross-sectional design. Longitudinal investigations of age-related memory effects may show different results altogether. This may be the case, especially, because the samples recruited for this thesis are fairly selective in that intellectually highly able adults with an interest in research participated. When following up the same ASD individuals over time, Howlin et al. (2014) found a steep decline in cognitive

functions in 25 % of older ASD individuals, preventing inclusion in further research studies. The lack of participation of individuals such as these may hide age-related memory differences in studied ASD populations.

Looking again at strategy use, it is also possible that the between-group difference in the use of the configuration strategy found in Wiener et al. (2013) may be explained by the fact that the authors had only screened their TD OA for mild cognitive impairments resulting from ageing, but younger and older TD adults had not been matched on cognitive ability. Therefore, it is possible that the older TD adults in the sample may have also had lower cognitive abilities confounding the data. In the current study, however, ASD and TD participants were well matched in terms of age and IQ. Finally, it is possible that the actual effect size of the between-group difference in configuration strategy use is small and would, therefore, require larger samples to be detected.

In general, the finding of an overall navigation deficit in ASD in this study may seem surprising, but there are two likely explanations, which will be discussed next. First, from a memory point of view, general difficulties in the spatial navigation performance in ASD may have occurred because of relational binding processes that are inherent in the task. According to Halford (1992; see Section 1.4.1.4), binary relations are necessary to process pairs of items, whereas in a ternary relation three pieces of information are set into relation. A same direction (egocentric) trial may be seen as a task that necessitates a participant to form a binary relation between one object and the direction of travel. Whereas to perform well in different direction (allocentric) trials, participants need to take account of both objects and their positions (right, left and front, back and vice versa) in relation to the travel direction and, therefore, several binary and ternary relations need to be formed. Both binary and ternary relations have been found to pose difficulties for ASD participants previously, for example, in Experiments 2 and 3 of this thesis. In addition, memory difficulties may have

also contributed to ASD participants' reduced navigation performance in terms of reduced memory for animal landmarks, which was also found to be an important predictor for navigation performance in the current study. The argument is further supported by the retrieval eye-movement data showing similar fixation durations and numbers of fixations on landmark animals in egocentric and allocentric trials in the ASD group, which may indicate reduced processing of relations between landmarks. This argument is also supported by correlations between navigation and eye-movement data showing that particularly allocentric navigation benefitted from a larger difference in fixation durations and number of fixations between landmark animals. Similar fixations on egocentric and allocentric trials may also indicate that ASD individuals did not identify allocentric trials as presenting the intersection coming from a different direction than at study and, therefore, presenting a new image. ASD participants may have confused newly presented allocentric with familiar egocentric images, reflecting reduced EM in ASD.

A second possible explanation for the overall navigation deficit in ASD found in this study is that the general difficulty in switching between navigation strategies in ASD along with the randomised presentation of allocentric and egocentric trials may have had a knock-on effect on same direction performance, decreasing performance overall in the ASD group. As already mentioned above, since switching requires a flexible adjustment both to and between different trial types, it is likely that cognitive flexibility and, therefore, EFs were important for this task. More perseverative errors for ASD participants in the current study (in line with Hughes et al., 1994; Ozonoff et al., 2004), as well as their importance for predicting navigation performance have highlighted the relevance of EFs for spatial navigation, in addition to memory, in the current study. Another factor that may have had an influence on reduced navigation performance in ASD is perspective-taking ability. Previous research highlighted the importance of perspective-taking ability in spatial navigation

(Kozhevnikov, Motes, Rasch & Blajenkova, 2006; Langdon, Coltheart, Ward & Catts, 2001), and De Condappa and Wiener (2016), using the same paradigm as the current study, suggested that allocentric trials can also be solved by using a perspective-taking approach rather than a configuration strategy. Given the difficulties ASD individuals present with ToM (see Sections 1.2.1, 1.4.2.5.1), and perspective-taking (e.g., Hamilton, Brindley & Frith, 2009; Rehfeldt, Dillen, Ziomek & Kowalchuk, 2007), difficulties in these areas may have played a role for the navigation deficit in the current study.

In addition to memory and EFs, differences in attention may have played a role in the spatial navigation difficulties in ASD, as indicated by encoding eye movements. In line with predictions, ASD individuals attended less to the animal landmarks. Although not apparent in the correlations between encoding eye movements and later navigation performance, it may still be possible that reduced attention to landmarks may have contributed to ASD individuals' reduced memory for the landmarks in the item test, as well as to difficulties with spatial navigation, as the use of environmental cues was found necessary for successful (allocentric) navigation (Bohbot et al., 2004). It is possible that the measures of fixation duration and number of fixations at encoding may not have been sensitive enough to pick up on the particular attention differences related to navigation difficulties in ASD. Specifically, it seems possible that not pure fixation time, but rather differences in a more complex fixation pattern, such as looking back and forth between landmarks and travel directions to form the basis for a cognitive map, would be a better predictor for navigation performance. However, reduced attention to landmarks at encoding in the ASD group in the current study replicated and extended the finding from Experiment 2, showing that different attentional preferences at encoding may contribute to memory as well as spatial navigation difficulties in ASD. Reduced fixations on landmarks also indicated less spontaneous use of cues inherent in the task, which raised the question if it is possible to improve task performance by the provision

of task support (Bowler et al., 1997). It seems likely, when using the same paradigm as in the current study, that instructing ASD individuals, explicitly, to encode the landmarks and their relations, and to use them as cues for their navigation, would enhance ASD participants' task performance. Similarly, explicitly informing participants about the different pieces of information that need to be taken into account and related to one another may increase task performance. Using the paradigm of the current study, this would mean that participants would be informed about the landmark animals and how their positions (left vs. right, front vs. back) and their relation to one another relate to the travel direction and the correct response for same and different direction trials. These possibilities should be investigated in future research.

By finding general navigation deficits independent of condition in ASD and the surprising effect of age on egocentric navigation, only partial support was found for the ageing analogy (Bowler, 2007), and the idea that the PFC and the hippocampus, affected by typical ageing (Hedden & Gabrieli, 2004), may also underlie memory difficulties observed in ASD. The parietal lobes would be another brain structure worth considering (Boucher & Mayes, 2012; Maister et al., 2013), since eye-movement data showed attention differences in ASD in the current study, and the parietal lobes have been reported to support attention (Behrmann, Geng & Shomstein, 2004; Han et al., 2004; Malhotra, Coulthard & Husain, 2009). They have also been shown to be involved in spatial navigation in addition to the hippocampus and the PFC (Moffat, 2009), and all three brain regions are considered to be part of the *default network* underlying functions, such as Remembering, ToM, EFT, and ABM (Spreng, Mar & Kim, 2009), with self-projection (Buckner & Carroll, 2007) and scene-construction (Hassabis & Maguire, 2007) as the processes supporting these functions. Evidence consistent with the idea of a disturbance to the default network in ASD has been reported by Lind et al. (2013), who found difficulties in spatial navigation that were related to

problems in ToM and EM. This interpretation fits with the idea of an involvement of perspective-taking ability in the spatial navigation difficulties in ASD.

To conclude, the present study shows general spatial navigation difficulties that were related to the ability to flexibly switch between different navigation strategies, as well as item memory and EFs. The role of EFs was particularly highlighted by findings of a stronger effect of age on egocentric navigation in ASD, suggesting that the demands on EFs in the task may have disabled the use of frontal lobe functions as a compensatory mechanism for navigation in ASD in the current study. Findings of reduced effects of age on allocentric navigation in ASD in the current study, replicated results of smaller age-related effects on order memory and R responses in ASD in Experiments 1 and 3. Replicating Experiment 2, eye movements at retrieval reflected reduced EM in ASD, and eye movements at encoding suggested attention differences as well as less spontaneous use of cues, which may have contributed further to the spatial navigation difficulties in ASD.

Taken together, although the studies of this thesis so far showed that other processes such as difficulties in EFs, relying on frontal lobe functioning, and attention differences, related to the functionality of the parietal cortex, contribute to memory and spatial navigation difficulties, all studies strongly pointed to difficulties in relational processing in ASD, which is related to hippocampal functioning (Opitz, 2010). EM, relational memory, and spatial navigation are all capacities of the hippocampus (Bohbot et al., 2004; Burgess, Maguire & O'Keefe, 2002; Davachi, 2006; Eichenbaum, 2007; Howard et al., 2001; Opitz, 2010). Difficulties in EM were found in Experiment 1 by showing reduced R responses. Experiments 2 and 3 reported reduced relational memory in ASD for location, order, and set information, and Experiment 4 found difficulties in spatial navigation in ASD. However, none of the studies so far has been completely conclusive in demonstrating abnormal hippocampal functioning in ASD. For example, in the case of Experiment 4, difficulties were

also found in egocentric memory related to caudate nucleus function (Bohbot et al., 2004), and EFs difficulties and attention abnormalities were also reported. Therefore, Experiment 5 used a new method to more directly assess atypical hippocampal functioning in ASD by adapting a paradigm from the animal learning literature (Aggleton et al., 2007, 2009; Sanderson et al., 2006). This paradigm tested structural learning, which is seen as the fundamental hippocampal mechanism underlying learning, memory, and spatial navigation (Sutherland & Rudy, 1989; Rudy & Sutherland, 1995). Difficulties in structural learning have been related, directly, to abnormal hippocampal functioning, in that rats with hippocampal lesions showed difficulties in performing the structural learning test compared to rats with sham lesions. Therefore, testing structural learning in ASD in Experiment 5 forms a direct test of hippocampal functioning in ASD.

5 Chapter 5: Structural learning

5.1 Experiment 5: Structural learning

5.1.1 Theoretical background

Structural learning[17] - a type of configural learning, where the spatial arrangement of the stimuli is important for task success (Aggleton et al., 2007, 2009; Sanderson et al., 2006), is crucial to an organism's adaptation to complex environments, and it has been proposed as the fundamental hippocampal mechanism underlying learning, memory, and spatial navigation (Sutherland & Rudy, 1989; Rudy & Sutherland, 1995). Like in all configural learning tasks, a combination of items rather than single items needs to be learned (Aggleton et al., 2007), and, in addition, the spatial or temporal relation between the items is important for structural learning (Aggleton et al., 2007). Regarding the function of spatial navigation (see Chapter 4), the hippocampus has been shown to be necessary for the creation of a cognitive/spatial map, representing the relation between a goal location and environmental cues (O'Keefe & Nadel, 1978). According to Schiller et al. (2015), echoing Tolman (1948), the same mechanism underlies a range of hippocampal functions that enable the organism to use information flexibly to guide behaviour. Damage to the hippocampus would, in this context, lead to inflexible behaviour (Rubin et al., 2014). Schiller et al. (2015) reported the coding of the temporal context of memories, visual, mental, and locomotive exploration of space, the organisation of knowledge to obtain expertise in a certain area of skill, "navigating" the social world (by defining relationships via dimensions), and the organisation of memories from different experiences as hippocampal functions.

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[17] While structural learning was tested with a Structural Discrimination task, Biconditional Discrimination and Transverse Patterning tasks were used to measure other forms of configural learning. Whereas the phrases structural and configural learning will be used to refer to the learning processes, Structural Discrimination, Biconditional Discrimination, and Transverse Patterning will refer to the tasks used to measure them.

Theories have for long suspected a role of the hippocampus in the (cognitive) differences observed in ASD (see Section 1.4.2.1; *amnesia parallel* - Boucher & Warrington, 1976; DeLong, 1992; Waterhouse, Fein & Modahl, 1996; *relational binding account* - Bowler et al., 2011). The theories have been supported by difficulties in various areas of functioning that are hippocampus-dependent in ASD, and that map onto Schiller et al.'s (2015) overview of processes that rely on the formation of a cognitive map. For example, difficulties in ASD resulting from differences in configural processing have been reported in the areas of face processing (Behrmann et al., 2006; Dawson, Webb & McPartland, 2005; Deruelle, Rondan, Salle-Collemiche, Bastard-Rosset & Da Fonséca, 2006), memory (see Sections 1.4.1, 2.1, 3.1, 3.2), and spatial navigation (Chapter 4). Finally, regarding memory organisation, reduced transfer of information in ASD has been found in various domains, such as perception (Plaisted et al., 1998a; Swettenham, 1996), language (D. L. Williams, Mazefsky, Walker, Minshew & Goldstein, 2014; D. L. Williams et al., 2015), and (meta-) memory (Gaigg et al. 2012; Wojcik et al. 2013).

Lesion studies in non-human animals have demonstrated an important role for the hippocampus (Aggleton et al., 2007), as well as for cortico-hippocampal interactions in structural learning (Aggleton et al., 2009), with lesions to the perirhinal cortex (Aggleton, Albasser, Aggleton, Poirier & Pearce, 2010), the fornix, or the thalamus (Aggleton et al., 2009) leaving structural learning intact. Lesions to the frontal cortex in rats (Butt & Bowman, 2002) and monkeys (Browning & Gaffan, 2008) also affected configural learning, most probably because of the connections between frontal and temporal cortices. Studies typically compared rats' performance on structural learning (measured with Structural Discrimination) with performance on other configural learning tasks (i.e., Biconditional Discrimination and Transverse Patterning; Sanderson et al., 2006). Biconditional Discrimination served as a control task to test whether rats were able to bind two elements to one another, and

Transverse Patterning measured their ability to alternate rules depending on the context. Structural Discrimination represented a combination of these two processes, and, in addition, the spatial arrangement of the stimuli was important for successful task performance. Simple Discrimination was included to test whether rats were able to discriminate two simple images. Rats with hippocampal lesions were found to perform similarly to sham lesioned rats on Simple Discrimination, Biconditional Discrimination, and Transverse Patterning, but they showed lower learning across all blocks of Structural Discrimination, as well as lower accuracy on the final structural test block (Sanderson et al., 2006). The rats' performance was above chance on all discriminations in all tasks, suggesting that they used structural and configural learning rather than some other strategy. Probe trials, presenting mirror images of originally studied images in the last test block of Biconditional Discrimination, assessed the degree of transfer to the mirror probe images, and ratio scores (correct answers probe trials/(correct answers original images + correct answers probe trials)) indicated better performance on probe images for rats with hippocampal lesions because of reduced learning of the structural arrangement of the images at study and, therefore, reduced transfer at test.

Following the literature reviewed above, the aims of this study were the following. First, it was aimed to investigate structural learning in ASD as the fundamental hippocampal mechanism underlying other cognitive processes such as memory and spatial navigation by adapting a task from the non-human animal learning literature using minimal verbal instructions. Second, it was aimed to include a number of control tasks, such as, Simple Discrimination, Biconditional Discrimination, and Transverse Patterning, and control measures, such as, measurements of response time and EFs, to exclude alternative reasons for potential difficulties in a Structural Discrimination task in ASD.

The tasks were adapted from the animal learning literature. In Simple Discrimination, participants were asked to learn to discriminate between two simple shapes. In Biconditional Discrimination, participants were presented with pairs of compound images and had to bind the two parts of a compound image in order to learn to discriminate it from the other item of the pair. In Transverse Patterning, participants were presented with simple patches, such as black or white, and had to learn to discriminate between them depending on the context, i.e., which shapes were presented together. As in the hand game rock-paper-scissors, correctness of a shape depended on which other shape it was presented with. The EF task also assessed the ability to alternate in that participants were asked to alternate between different coloured circles. Structural Discrimination, the task used to assess structural learning, formed a combination of Biconditional Discrimination and Transverse Patterning, in that participants were presented with mirror images of compound stimuli. Participants needed to bind the two parts of a compound stimulus and, in addition, they needed to consider the context, i.e., which part of the image was presented on which side in order to learn which of the two mirror images was correct.

To examine the first aim, accuracy scores for structural learning derived from the Structural Discrimination task were inspected for the four learning blocks and the test block. Ratio scores (correct answers probe trials/(correct answers original images + correct answers probe trials)) were computed, and performance on the three discriminations was compared against chance. If ASD participants show difficulties in structural learning, their accuracy will be lower on the Structural Discrimination learning and test blocks compared to TD individuals. If ASD individuals show difficulties in transfer of information from study to test, their ratio scores will indicate better performance on probe compared to originally studied trials. If persons with ASD use structural learning to solve the Structural Discrimination task, their performance will be above chance on all three discriminations. Regarding the second

aim, accuracy scores were inspected for Simple Discrimination, Biconditional Discrimination, and Transverse Patterning (learning and test blocks), response times for Structural Discrimination were analysed, and performance on the EF task was examined. If ASD participants show specific difficulties in structural learning, they will show no difficulties compared to TD individuals in discriminating between two simple shapes, in binding two elements for discrimination, or in alternating rules in discrimination depending on the context. In addition, structural learning difficulties will not be caused by a speed-accuracy trade-off in the Structural Discrimination task and they will also not be related to potential difficulties in EFs.

5.1.2 Predictions

Based on theories suspecting the hippocampus as a neural substrate for the cognitive differences in ASD (Section 1.4.2.1), and the evidence just outlined, no between-group differences were expected for Simple and Biconditional Discrimination as well as Transverse Patterning. However, ASD participants were predicted to show specific difficulties in Structural Discrimination with lower learning on all blocks and lower accuracy on the final test block. Probe trials were included for Biconditional and Structural Discrimination to measure the extent of transfer from studied to new test images in the two groups. It was predicted that ASD individuals would show better performance on the probe images because of reduced encoding of structural relations inherent in the study images and, therefore, reduced transfer of information from study to test. It was predicted that ASD individuals would use structural learning in the Structural Discrimination task. Finally the role of EFs in the context of structural learning was assessed. Potential difficulties in EFs were predicted to be unrelated to difficulties in structural learning in ASD.

5.1.3 Methods

5.1.3.1 Participants

Sanderson et al. (2006) tested six participants on average in each group for each of the three tasks. To increase statistical power to detect a possible between-group difference between ASD and TD individuals, overall 114 adults took part in either of three tasks, resulting in 19 TD and 19 ASD participants for each task. Individuals were closely matched on gender, X^2_{max} < 2.18, p_{min} > .14, and CA, t < 0.40, p > .69, Cohen's d < 0.08, 95 % CI_{max}(-0.29, 0.44), and they were individually matched on VIQ/VCI, PIQ/PRI, and FIQ, t_{max} < 0.61, p_{min} > .54, Cohen's d_{max} < 0.12, 95 % CI_{max}(-0.25, 0.48), as measured by the WAIS-III[UK] or WAIS-IV[UK] (The Psychological Corporation, 2000, 2008). The participant characteristics are displayed in detail in Tables 5.1 - 5.3. All participants (except one ASD individual in Biconditional Discrimination) filled in the AQ (Baron-Cohen et al., 2001), confirming significantly higher scores for the ASD compared to the TD group. Overall, 37 out of the 57 ASD individuals had time to take part in an assessment with the ADOS (Lord et al., 1989). Out of these, eight individuals scored just below the total cut-off score on this instrument, but they were nevertheless included in the sample, since they had all received a clinical diagnosis of an ASD. As explained in Section 2.1.2.1, the 39 % of ASD participants that reported comorbidities and/or use of psychotropic medication remained in the sample for the current study. Depression (55 %), anxiety disorder (18 %), dyslexia (14 %), and ADHD (9 %) were most common. In addition, OCD (5 %) and schizophrenia (5 %) were alos reported as comorbid disorders. Further, 50 % of ASD individuals took antidepressants, and 18 % used antipsychotic medication. ASD individuals with and without comorbidities and medication use did not differ significantly in terms of gender, $X^2 = 0.67$, $p = .42$, CA, VIQ/VCI, PIQ/PRI, and FIQ, t_{max} < 0.61, p_{min} > .54, Cohen's d_{max} < 0.17, 95 % CI_{max}(-0.37, 0.70) and analysing the data without these individuals did not change the direction of the results reported below.

Table 5.1

Descriptive statistics for ASD and TD individuals, who participated in the Structural Discrimination task of Experiment 5.

| | ASD (16m, 3f) | | TD (12m, 7f) | | | | Cohen's | |
	M	*SD*	*M*	*SD*	*t*(df)	*p*	*d*	CI
Age (years)	42.02	13.3	41.06	13.7	0.22 (36)	.83	0.07	-0.57, 0.71
VIQ/VCI[a]	111	16.8	110	14.0	0.14 (36)	.89	0.04	-0.59, 0.68
PIQ/PRI[b]	104	16.8	105	15.5	0.06 (36)	.95	0.02	-0.62, 0.66
FIQ[c]	108	17.0	108	14.0	0.15 (34)	.88	0.05	-0.61, 0.70
CTT2[d]	0.37	0.7	0.26	0.6	0.52 (36)	.61	0.17	-0.47, 0.80
AQ[e]	32.68	7.4	15.79	5.2	8.14 (36)	.00	2.64	1.72, 3.45
ADOS-C[f]	3.00 (1-6)	1.4						
ADOS-RSI[g]	4.85 (1-8)	1.7						
ADOS-Total[h]	7.85 (5-14)	2.4						
ADOS-Im[i]	1.17 (0-2)	0.7						
ADOS-SB[j]	1.00 (0-5)	1.5						

Note. [a]VIQ - Verbal IQ (WAIS-III[UK]) or VCI - Verbal Comprehension Index (WAIS-IV[UK]). [b]PIQ - Performance IQ (WAIS-III[UK]) or PRI - Perceptual Reasoning Index (WAIS-IV[UK]). [c]Full-scale IQ (WAIS-III[UK] or WAIS-IV[UK]) was available for 19 ASD and 17 TD individuals. [d]Color Trails Test Trial 2 - errors. [e]AQ - Autism-Spectrum Quotient. [f]ADOS - Communication subscale. [g]ADOS - Reciprocal Social Interaction subscale. [h]ADOS Total score - Communication + Reciprocal Social Interaction. [i]ADOS - Imagination/Creativity subscale. [j]ADOS - Stereotyped Behaviours and Restricted Interests subscale. The ADOS was available for 13 individuals. ADOS scores are presented with range in brackets.

Table 5.2

Descriptive statistics for ASD and TD individuals, who participated in the Biconditional Discrimination task of Experiment 5.

	ASD (15m, 4f)		TD (16m, 3f)			Cohen's		
	M	*SD*	*M*	*SD*	*t*(df)	*p*	*d*	CI
Age (years)	43.85	13.0	43.57	11.9	0.07 (36)	.94	0.02	-0.61, 0.66
VIQ/VCI[a]	110	18.0	109	14.2	0.23 (36)	.82	0.07	-0.56, 0.71
PIQ/PRI[b]	105	17.1	105	16.1	0.00 (36)	1	0	-0.64, 0.64
FIQ[c]	108	17.1	107	15.3	0.28 (33)	.79	0.09	-0.57, 0.75
AQ[d]	36.56	7.4	13.74	6.5	9.91 (35)	.00	3.26	2.22, 4.16
ADOS-C[e]	2.10 (0-5)	1.5						
ADOS-RSI[f]	6.80 (3-12)	3.5						
ADOS-Total[g]	8.90 (3-17)	4.1						
ADOS-Im[h]	1.30 (0-2)	0.8						
ADOS-SB[i]	1.90 (0-3)	1.1						

Note. [a]VIQ - Verbal IQ (WAIS-III[UK]) or VCI - Verbal Comprehension Index (WAIS-IV[UK]). [b]PIQ - Performance IQ (WAIS-III[UK]) or PRI - Perceptual Reasoning Index (WAIS-IV[UK]). [c]Full-scale IQ (WAIS-III[UK] or WAIS-IV[UK]) was available for 18 ASD and 17 TD individuals. [d]AQ - Autism-Spectrum Quotient was available for 18 ASD and 19 TD individuals. [e]ADOS - Communication subscale. [f]ADOS - Reciprocal Social Interaction subscale. [g]ADOS Total score - Communication + Reciprocal Social Interaction. [h]ADOS - Imagination/Creativity subscale. [i]ADOS - Stereotyped Behaviours and Restricted Interests subscale. The ADOS was available for 10 individuals. ADOS scores are presented with range in brackets.

Table 5.3

Descriptive statistics for ASD and TD individuals, who participated in the Transverse Patterning task of Experiment 5.

| | ASD (16m, 3f) | | TD (15m, 4f) | | | Cohen's | | |
	M	SD	M	SD	t(df)	p	d	CI
Age (years)	43.37	12.9	41.77	12.8	0.38 (36)	.70	0.12	-0.51, 0.76
VIQ/VCI[a]	115	16.1	112	12.7	0.71 (36)	.49	0.23	-0.41, 0.86
PIQ/PRI[b]	108	15.0	107	13.4	0.17 (36)	.87	0.06	-0.58, 0.69
FIQ[c]	111	16.0	109	14.4	0.33 (29)	.74	0.12	-0.60, 0.83
AQ[d]	36.32	7.7	13.58	6.8	9.65 (36)	.00	3.13	2.13, 4.00
ADOS-C[e]	2.50 (0-5)	1.5						
ADOS-RSI[f]	6.29 (3-13)	2.8						
ADOS-Total[g]	8.79 (5-17)	3.5						
ADOS-Im[h]	1.21 (0-2)	0.7						
ADOS-SB[i]	1.29 (0-3)	0.8						

Note. [a]VIQ - Verbal IQ (WAIS-III[UK]) or VCI - Verbal Comprehension Index (WAIS-IV[UK]). [b]PIQ - Performance IQ (WAIS-III[UK]) or PRI - Perceptual Reasoning Index (WAIS-IV[UK]). [c]Full-scale IQ (WAIS-III[UK] or WAIS-IV[UK]) was available for 18 ASD and 13 TD individuals. [d]AQ - Autism-Spectrum Quotient. [e]ADOS - Communication subscale. [f]ADOS - Reciprocal Social Interaction subscale. [g]ADOS Total score - Communication + Reciprocal Social Interaction. [h]ADOS - Imagination/Creativity subscale. [i]ADOS - Stereotyped Behaviours and Restricted Interests subscale. The ADOS was available for 14 individuals. ADOS scores are presented with range in brackets.

5.1.3.2 Materials

Materials and procedures were adapted from the rodent literature (Aggleton et al., 2007; Sanderson et al., 2006). All tasks involved minimal verbal instructions. Black and white images (see Figure 5.1) were presented on a touch-sensitive 12-inch laptop screen.
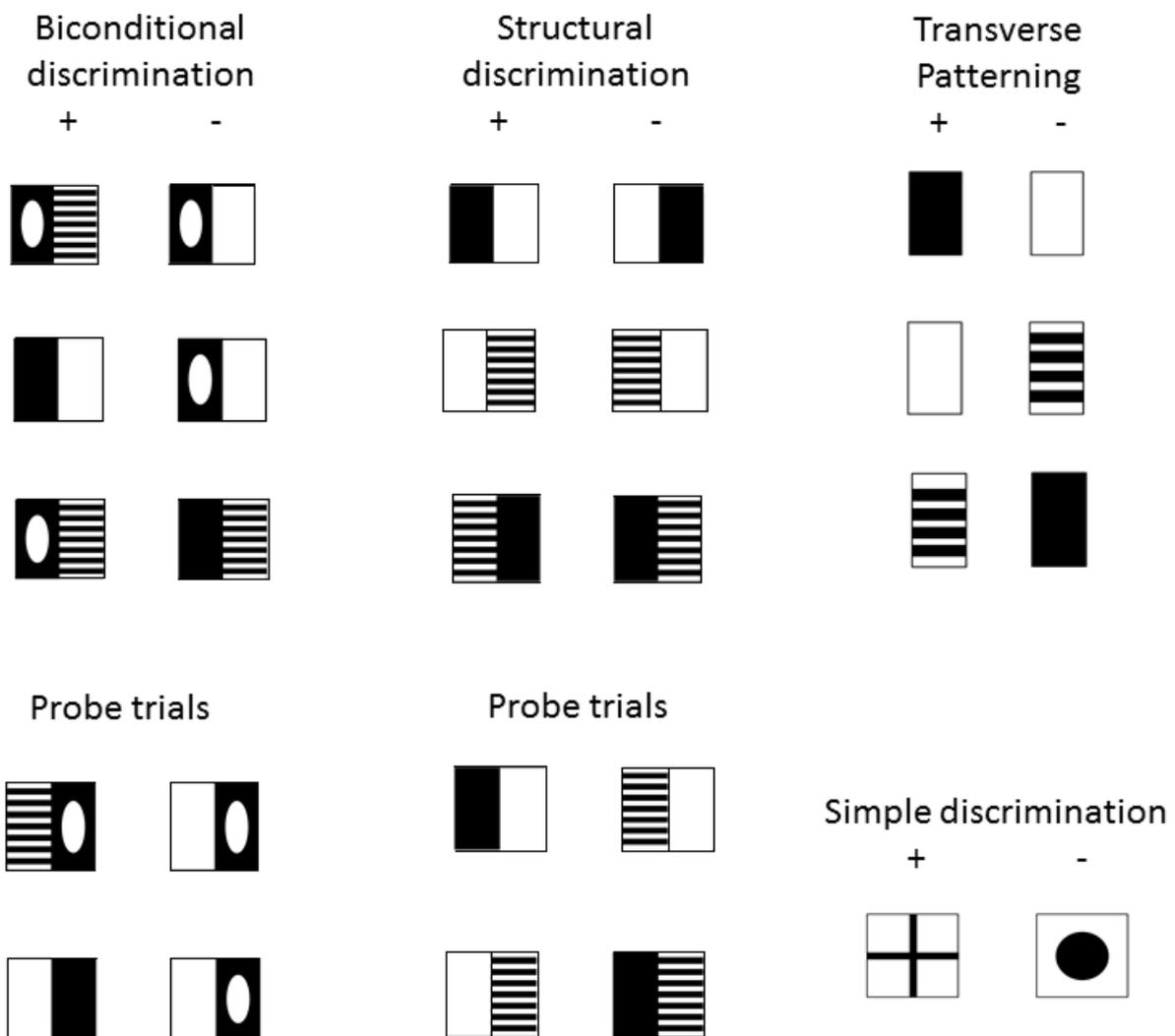
Figure 5.1. Examples of the stimuli for the tasks used in Experiment 5. Simple Discrimination (bottom right) was part of all three tasks. As opposed to Transverse Patterning (top right), Structural (middle) and Biconditional Discrimination (left) included probe trials presenting re-paired stimuli for Structural Discrimination (bottom middle) and mirror images for Biconditional Discrimination (bottom left) in Block 5. The stimuli presented below the plus sign were reinforced in the example.

A detailed overview of the stimuli and reinforcement contingencies is presented in Tables A3.1 - A3.3 in Appendix 3.

5.1.3.3 Procedure

After a practice in Simple Discrimination, participants took part in one of three tasks (Structural Discrimination, Biconditional Discrimination, or Transverse Patterning), with two matched participants (one TD and one ASD individual with similar IQs) receiving the same version of the task. Trials of *Simple Discrimination* (using different stimuli compared to the practice) were then included in every task to test if participants in both groups learned which of two simple shapes was the correct (reinforced) one, independent of the presentation side on the screen, and to discourage perseveration (Sanderson et al., 2006). The experimenter stayed in the room with the participant to be available for questions.

Each task consisted of five blocks with a pause after each block, which participants chose to terminate to continue the task by pressing a pause button on the laptop screen. In every trial, two images were presented simultaneously, and participants were asked to pick the correct image by touching it. Feedback (a smiling cartoon face for correct or a frowning cartoon face for incorrect responses) was presented on-screen, and participants were told to aim for correctness. Which images were reinforced, and in which block they appeared was fully counterbalanced between participants. The presentation side of the reinforced stimuli was counterbalanced within participants. Accuracy and reaction times were measured for every block.

Every trial started with the presentation of a blank screen for 1 s, followed by the two images on the left and right side of the screen, which were displayed until participants touched one of the images. Feedback stayed on-screen for 1.5 s, after which the next trial started (e.g., in Block 1, there were 10 experimental trials and two trials of Simple Discrimination). In every block, participants had to learn to criterion (e.g., in Block 1, the

criterion was 80 % correct on experimental trials and 50 % correct on Simple Discrimination; see Tables A3.1 - A3.3 in Appendix 3 for details). If the criterion was reached, the task continued with the next block, otherwise the block was repeated a maximum of two times, after which the programme continued automatically to the next block. Every task started with the presentation of one pair of experimental images. One new pair of images was added in every block (except for Block 3 of Biconditional Discrimination, which introduced two new pairs), until all shapes were repeated in Block 4. Whereas Block 5 was the same as Block 4 for Transverse Patterning, in Block 5 in Biconditional and Structural Discrimination studied images were presented intermixed with new probe trials.

Structural Discrimination (Figure 5.1 middle), as a combination of Biconditional Discrimination and Transverse Patterning, included three simultaneous discriminations presenting three pairs of mirror images of compound stimuli consecutively. The use of less discriminations would have made other strategies than structural learning possible for accurate task performance, for example, a single pair of Structural Discrimination was also solvable by processing single elements rather than compound images (a process necessary for Transverse Patterning). Structural Discrimination required participants to bind two elements together and, in addition, to bind them to their spatial arrangement, for example, out of *black/white* vs. *white/black*, the image with *black* on the left side was reinforced, whereas out of *black/striped* vs. *striped/black*, *black* had to be on the right side of *striped* for the image to be correct. Probe trials in Block 5 were re-pairings of studied images that had never been presented together previously (Figure 5.1 bottom middle), for example, the familiar forms of *black/white* vs. *black/striped* formed a new pair. Probe trials were included to measure the extent to which the structural arrangement of the stimuli had been processed, and whether transfer had taken place, as these trials were not solvable as Transverse Patterning.

In *Biconditional Discrimination* (Figure 5.1 left), participants studied four simultaneous discriminations, which were presented consecutively in the form of four pairs of compound images. The task included the binding of two elements, where correct answers were possible with or without taking the spatial arrangement of the stimuli into account. For example, in the pair *black/white* vs. *black/striped*, it was possible that *black* was presented on the left or the right side of *white* or *striped*. The pair consisting of *black* and *white* was always the correct image. Probe trials in Block 5 measured the extent to which participants processed the spatial arrangement of the stimuli by presenting mirror images of previously studied images, while keeping the pairs intact (Figure 5.1 bottom left).

In *Transverse Patterning* (see Figure 5.1 right), a second control task, participants had to learn the contingencies between the three simple shapes of *black*, *white*, and *striped*, when they were presented in pairs. Analogous to the rules of the hand game rock-paper-scissors, where rock beats scissors, scissors beat paper, and paper beats rock, participants needed to learn that *black* was correct, when presented with *white*, but when it was presented with *striped*, *striped* was correct. *White* was only correct when presented with *striped* (Figure 5.1 right).

Configural learning tests are complex and participants sometimes present inflexible response patterns in these tasks (Sanderson et al., 2006). Therefore, attentional shifting was assessed by measuring the number of errors made on Trial 2 of the paper-pencil Colour Trails Test (CTT, D'Elia, Satz, Uchiyana & White, 1996), as this has been shown to be sensitive to frontal lobe damage (Kopp et al., 2015). In Trial 1 of this test, measuring sustained attention, participants are asked to draw a line connecting yellow and pink circles with the numbers 1 - 25 in increasing order, by ignoring the different colours of the circles. In Trial 2, a participant is asked to connect circles by, additionally, alternating colours, measuring attentional shifting.

5.1.4 Results

The data were analysed with Chi-Squared Tests for nominal data, bivariate correlations, t-tests, and repeated measures ANOVAs and ANCOVAs. In case of significant differences, Bonferroni corrected post hoc tests were calculated, and GGC was used, where the Sphericity assumption was violated. The significance level of .05 was chosen for all tests and Cohen's *d* and partial Eta-Squared are reported as measures of effect size.

5.1.4.1   Accuracy

5.1.4.1.1   Simple Discrimination

Accuracy (percentage correct, Figure 5.2) was significantly above chance in all five blocks for both groups, all $t > 6.35$, all $p < .001$.
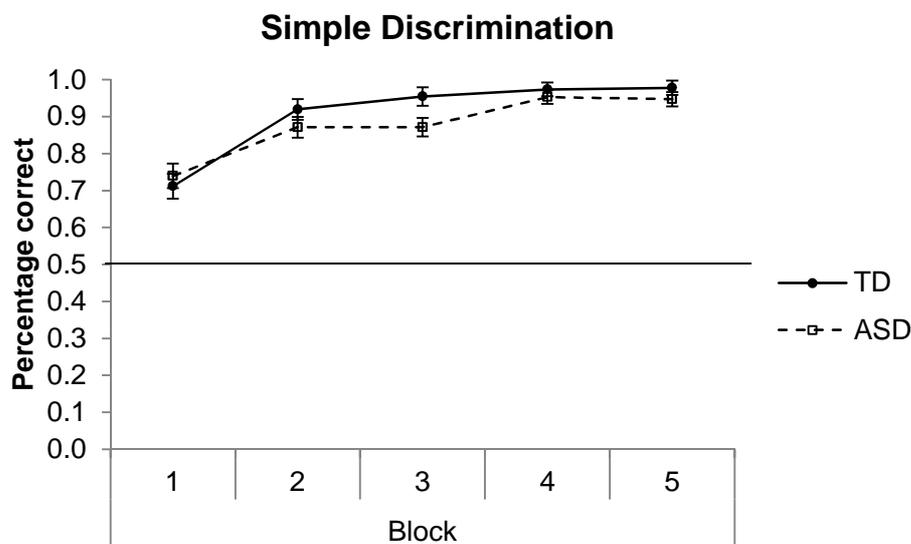
Figure 5.2. Accuracy as percentage correct for Simple Discrimination for the five blocks of the task, averaged across Structural Discrimination, Biconditional Discrimination, and Transverse Patterning, for ASD and TD individuals of Experiment 5, with the horizontal line indicating chance performance. The data are presented as mean ± SEM.

A 2 (Group [ASD, TD]) x 3 (Task [Structural Discrimination, Biconditional Discrimination, Transverse Patterning]) x 5 (Block [1, 2, 3, 4, 5]) repeated measures ANOVA revealed a significant main effect of *Block*, $F(1.91, 206.60) = 41.06$, $p < .001$, $\eta_p^2 = .28$, GGC. No other main effects or interactions were significant, $F_{max} < 1.80$, $p_{min} > .17$, $\eta_p^2{}_{max} < .02$, indicating similar Simple Discrimination learning over blocks in all three tasks in both groups.

5.1.4.1.2 Experimental tasks

Performance of both groups was significantly above chance on all blocks in all three tasks, all $t > 2.90$, all $p < .01$, (see Figures 5.3, 5.5, 5.7).

5.1.4.1.2.1 Structural Discrimination

5.1.4.1.2.1.1 Learning

Accuracy scores (Figure 5.3) were analysed with a 2 (Group [ASD, TD]) x 5 (Block [1, 2, 3, 4, 5]) repeated measures ANOVA.
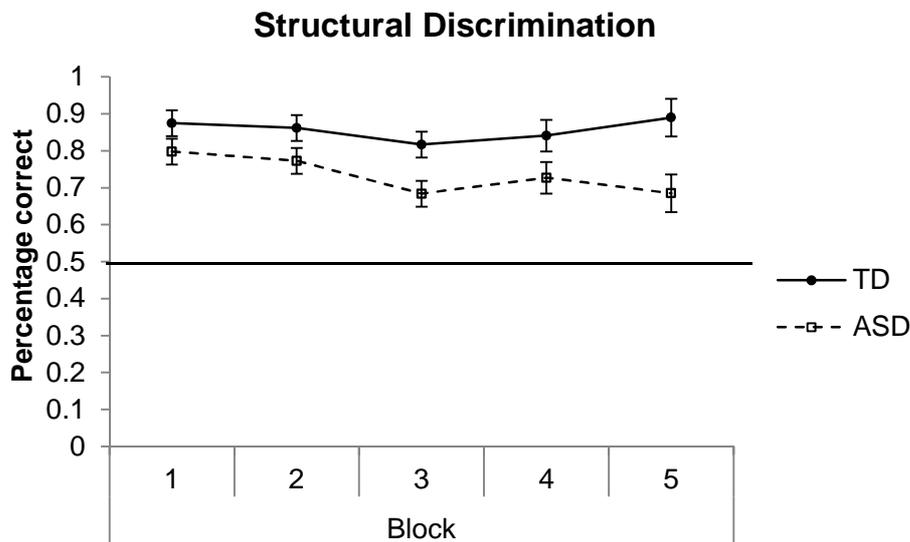
*Figure 5.3.* Accuracy as percentage correct for the five blocks of Structural Discrimination for ASD and TD participants of Experiment 5, with the horizontal line indicating chance performance. The data are presented as mean ± SEM.

The test showed a significant main effect of *Group*, $F(1,36) = 6.74$, $p < .05$, Cohen's $d = 0.84$, 95 % CI(0.16, 1.49), with lower performance in the ASD ($M = 0.73$, $SD = 0.15$) compared to the TD group ($M = 0.86$, $SD = 0.15$), with some individuals in both groups needing three attempts or not reaching criterion at a certain block (see Table 5.4). A significant main effect of *Block*, $F(2.73, 98.25) = 3.64$, $p < .05$, $\eta_p^2 = .09$, GGC, as well as a significant quadratic effect of *Block*, $F(1,36) = 6.22$, $p < .05$, $\eta_p^2 = .15$, indicated a decrease in performance from Blocks 1 to 3, which was followed by a later performance increase in Blocks 4 and 5. No Group x Block interaction was found, $F(2.73,98.25) = 2.10$, $p = .11$, $\eta_p^2 = .06$, GGC.

Table 5.4

Numbers of ASD and TD individuals, who needed three attempts or did not reach criterion at a certain block in each of the three tasks of Experiment 5.

Block	Structural task		Biconditional task		Transverse Patterning	
	ASD	**TD**	**ASD**	**TD**	**ASD**	**TD**
1	4	2	2	0	2	1
2	5	4	3	3	3	0
3	11	8	7	4	4	8
4	9	5	3	4	5	7

Note. In Block 5, the final test stage of each task, there was no learning criterion.

The data were analysed further by testing whether participants from both groups had used structural learning, or whether they had learned just one or two out of the three pairs. Block 4 constituted the strictest test of structural learning, as it presented all three pairs in randomised order. Performance on each of the pairs was ranked according to best, middle, and worst for every participant to test if their worst discrimination was greater than chance. Whereas TD

individuals performed significantly better than chance on all three discriminations ($M_{min} = 0.72$, $SD_{min} = 0.25$), all $p < .01$, ASD individuals' performance was greater than chance only for their two best discriminations ($M_{min} = 0.73$, $SD_{min} = 0.23$), both $p < .001$, with their worst discrimination not different from chance ($M = 0.58$, $SD = 0.28$), $p = .24$, suggesting that they did not acquire structural learning, but that they rather used some other strategy to perform the task.

5.1.4.1.2.1.2 Test

The analysis of differences between probe trials and originally studied pairs (Figure 5.4) with a 2 (Group [ASD, TD]) x 2 (Trial type [studied, probe]) repeated measures ANOVA revealed a significant main effect of *Group*, $F(1,36) = 4.71$, $p < .05$, Cohen's $d = 0.70$, 95 % CI(0.03, 1.34), with higher performance for the TD ($M = 0.87$, $SD = 0.19$) compared to the ASD group ($M = 0.73$, $SD = 0.19$). A significant *Group x Trial type* interaction, $F(1,36) = 10.49$, $p < .01$, $\eta_p^2 = .23$, showed that TD participants only performed better on studied pairs ($M_{TD} = 0.89$, $SD_{TD} = 0.15$; $M_{ASD} = 0.69$, $SD_{ASD} = 0.28$), $p < .01$, Cohen's $d = 0.92$, 95 % CI(0.23, 1.57), but not probe pairs ($M_{TD} = 0.85$, $SD_{TD} = 0.19$; $M_{ASD} = 0.78$, $SD_{ASD} = 0.18$), $p = .26$, Cohen's $d = 0.36$, 95 % CI(-0.28, 1.00), because the ASD group performed significantly better in probe compared to studied pairs, $p < .01$, Cohen's $d = 0.45$, 95 % CI(-0.20, 1.09). The main effect of Trial type was not significant, $F(1,36) = 1.24$, $p = .27$, Cohen's $d = 0.12$, 95 % CI(-0.34, 0.56).

A significantly higher ratio score (probe/(probe + studied); see Sanderson et al., 2006) for ASD ($M = 0.55$, $SD = 0.07$) compared to TD ($M = 0.48$, $SD = 0.03$) participants, $t(36) = 3.42$, $p < .01$, Cohen's $d = 1.11$, 95 % CI(0.40, 1.77), indicated a bigger difference between performance on studied and probe trials in the ASD group.

Structural Discrimination
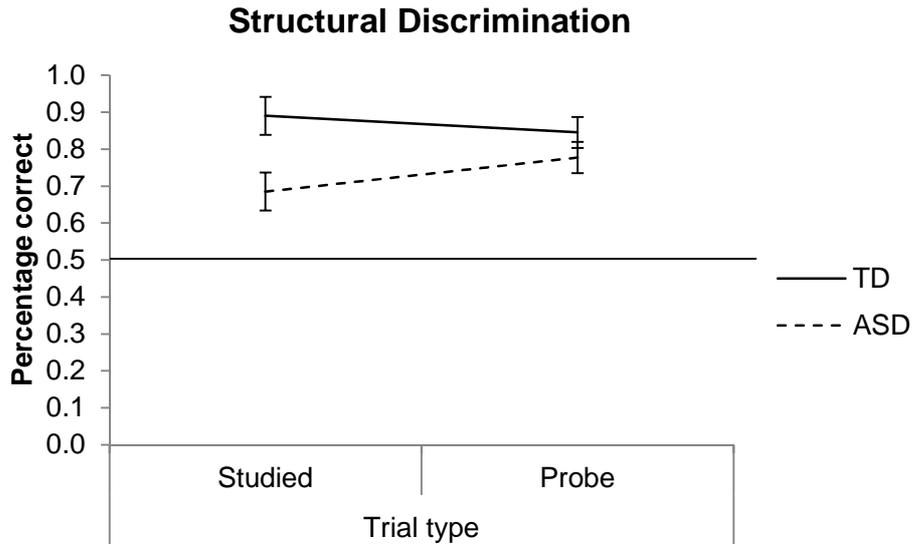
Figure 5.4. Accuracy as percentage correct for studied and probe trials in Block 5 for Structural Discrimination for ASD and TD participants in Experiment 5, with the horizontal line indicating chance performance. The data are presented as mean ± SEM.

5.1.4.1.2.1.3   Relation to executive functions

Having established that there were no significant between-group differences in the CTT2 (Table 5.1), bivariate correlation analysis showed significant negative correlations between CTT2 errors and performance on studied and probe trials of Block 5 of the Structural Discrimination test (Table 5.5), indicating the more errors participants made on the CTT2, the worse was their structural learning.

Because of a lack of group differences in CTT2, and because of the significant correlations with the performance measure of the structural task, CTT2 was used legitimately as a covariate (Miller & Chapman, 2000). ANCOVAs analysing Structural Discrimination learning and test performance, statistically controlling for the influence of EFs on the task by entering CTT2 as a covariate, left the pattern of results reported above unchanged.

Table 5.5

Bivariate correlations between performance on studied and probe trials for Structural Discrimination and executive functions, as measured by CTT2 errors, for ASD and TD groups in Experiment 5.

	ASD		TD		Total	
	Studied	**Probe**	**Studied**	**Probe**	**Studied**	**Probe**
CTT2	-.51*	-.39	-.46*	-.51*	-.43**	-.44**

Note. [a]Color Trails Test Trial 2 - errors. *significant at $p < .05$. **significant at $p < .01$.

5.1.4.1.2.2   Biconditional Discrimination

5.1.4.1.2.2.1   Learning

Percentage correct learning data in Figure 5.5 were analysed with a 2 (Group [ASD, TD]) x 5 (Block [1, 2, 3, 4, 5]) repeated measures ANOVA.
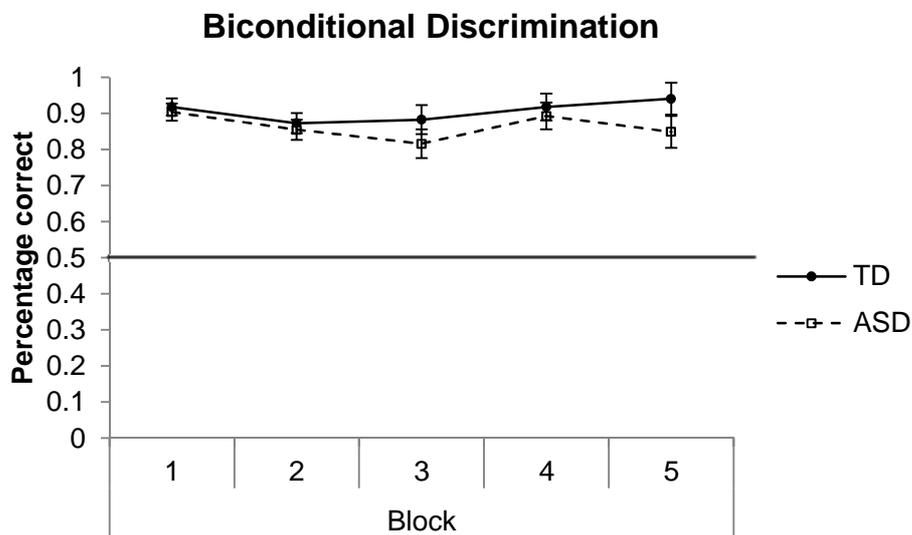
Figure 5.5. Accuracy as percentage correct for the five blocks of Biconditional Discrimination for ASD and TD participants of Experiment 5, with the horizontal line indicating chance performance. The data are presented as mean $\pm$ SEM.

The test showed a marginal main effect of *Block*, $F(2.74, 98.64) = 2.71$, $p = .05$, $\eta_p^2 = .07$, GGC, with a decrease in performance from Blocks 1 to 3, followed by a slight increase in performance in Block 4. This result pattern was confirmed by a significant quadratic effect of *Block*, $F(1,36) = 7.19$, $p < .05$, $\eta_p^2 = .17$. There was no main effect of Group or Group x Block interaction, $F_{max} < 1.20$, $p_{min} > .29$, $\eta_{p\,max}^2 < .04$. Table 5.4 presents the number of individuals that needed three attempts or did not reach criterion at a certain block.

5.1.4.1.2.2.2 Test

Performance on probe and studied trials (Figure 5.6) were compared using a 2 (Group [ASD, TD]) x 2 (Trial type [studied, probe]) repeated measures ANOVA.
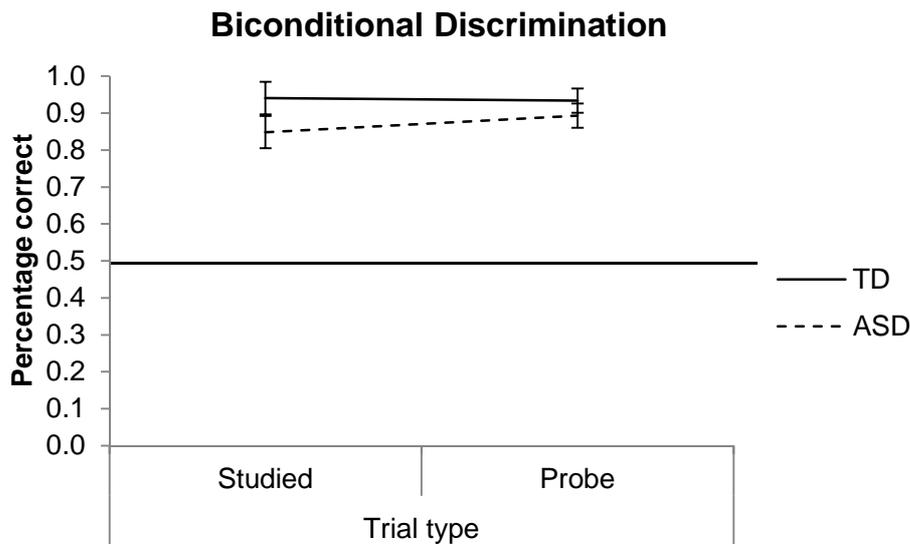
Figure 5.6. Accuracy as percentage correct for studied and probe trials in Block 5 for Biconditional Discrimination for ASD and TD individuals in Experiment 5, with the horizontal line indicating chance performance. The data are presented as mean ± SEM.

The analysis showed a marginal *Group x Trial type* interaction, $F(1,36) = 3.17$, $p = .08$, $\eta_p^2 = .08$, with the ASD group performing better in probe ($M = 0.89$, $SD = 0.17$) compared to initially studied trials ($M = 0.85$, $SD = 0.25$), $p < .05$, Cohens $d = 0.26$, 95 % CI(-0.38, 0.90).

No main effects were significant, $F_{max} < 1.65$, $p_{min} > .20$, Cohen's $d_{max} < 0.12$, 95 % CI_{max}(-0.34, 0.56), nor was there a significant difference between ASD ($M = 0.52$, $SD = 0.06$) and TD ($M = 0.50$, $SD = 0.02$) participants' ratio scores, $t(36) = 1.69$, $p = .11$, Cohen's $d = 0.55$, 95 % CI(-0.11, 1.18).

5.1.4.1.2.3   Transverse Patterning

5.1.4.1.2.3.1   Learning

Accuracy data, presented in Figure 5.7, were analysed using a 2 (Group [ASD, TD]) x 5 (Block [1, 2, 3, 4, 5]) repeated measures ANOVA.
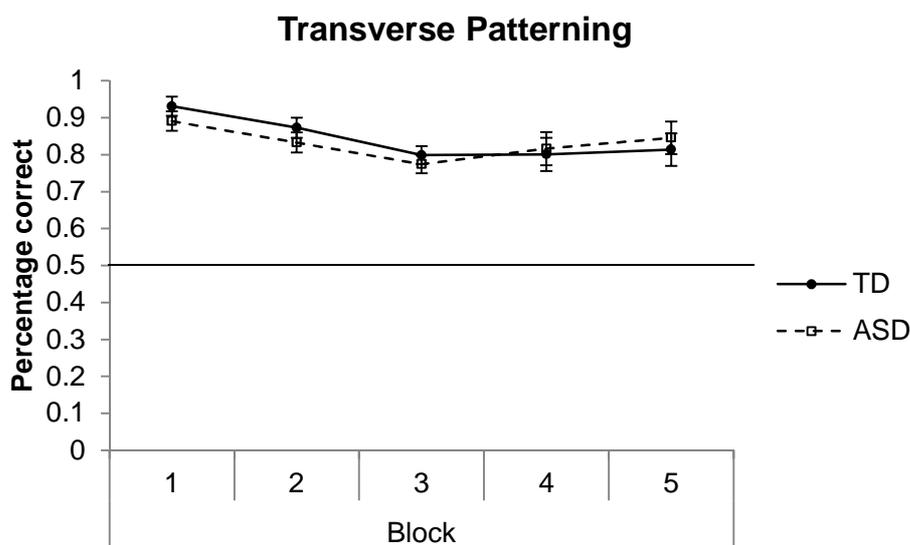
Figure 5.7. Accuracy as percentage correct for five blocks of Transverse Patterning for ASD and TD participants of Experiment 5, with the horizontal line indicating chance performance. The data are presented as mean $\pm$ SEM.

The test revealed a significant main effect of *Block*, $F(2.73, 98.31) = 7.21$, $p < .001$, $\eta_p^2 = .17$, GGC, with a performance decrease in Blocks 1 to 3, and a slight increase in performance in Blocks 4 and 5, which was supported by a significant quadratic effect of *Block*, $F(1,36) = 19.23$, $p < .001$, $\eta_p^2 = .35$. There was no main effect of Group or Group x Block interaction,

$F_{max} < 0.88$, $p_{min} > .44$, $\eta_{p\ max}^{2} < .03$. An overview of the number of individuals that needed three attempts or did not reach criterion at a certain block in this task is presented in Table 5.4.

5.1.4.2 Response time

Response times were investigated to test whether ASD participants showed quicker response times, next to lower accuracy on the structural task, which would indicate that group differences may have been caused by a speed-accuracy trade-off in the ASD group.

5.1.4.2.1 Simple Discrimination

The response times, displayed in Figure 5.8, were analysed with a 2 (Group [ASD, TD]) x 3 (Task [Structural Discrimination, Biconditional Discrimination, Transverse Patterning]) x 5 (Block [1, 2, 3, 4, 5]) repeated measures ANOVA.
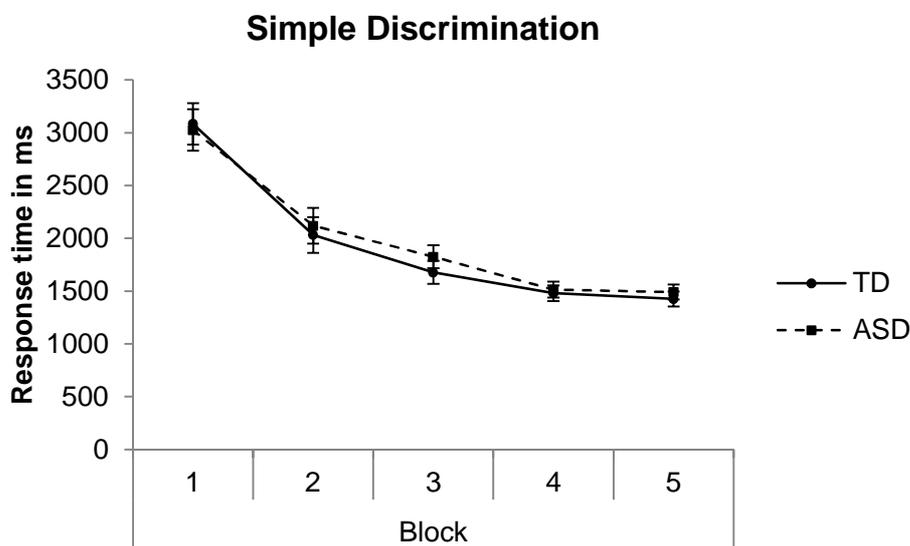
Figure 5.8. Response times in ms for the five blocks of Simple Discrimination, averaged across Structural Discrimination, Biconditional Discrimination, and Transverse Patterning, for ASD and TD participants of Experiment 5. The data are presented as mean ± SEM.

The analysis revealed a significant main effect of *Block*, $F(2.15,232.66) = 77.46$, $p < .0001$, $\eta_p^2 = .42$, GGC, with decreasing response times across blocks. No other main effects or interactions were significant, $F_{max} < 2.28$, $p_{min} > .10$, $\eta_p^2{}_{max} < .05$, indicating similar response times for Simple Discrimination for both groups in all three tasks.

5.1.4.2.2 Experimental tasks

5.1.4.2.2.1 Learning

Response times, presented in Figure 5.9, were analysed with 2 (Group [ASD, TD]) x 5 (Block [1, 2, 3, 4, 5]) repeated measures ANOVAs. The tests showed significant main effects of *Block* for all three experimental tasks, indicating a decrease (Blocks 1 to 2), followed by an increase (Blocks 2 to 5) in response times across blocks for Structural Discrimination, $F(2.03,73.11) = 3.51$, $p < .05$, $\eta_p^2 = .09$, GGC, a decrease in response times in Biconditional Discrimination, $F(2.61,94.01) = 3.43$, $p < .05$, $\eta_p^2 = .09$, GGC, and an increase in response times across blocks in Transverse Patterning, $F(2.58,92.76) = 8.26$, $p < .0001$, $\eta_p^2 = .19$, GGC. No main effects of Group or Group x Block interactions were significant, $F_{max} < 1.48$, $p_{min} > .23$, $\eta_p^2{}_{max} < .04$.

Biconditional Discrimination

Transverse Patterning
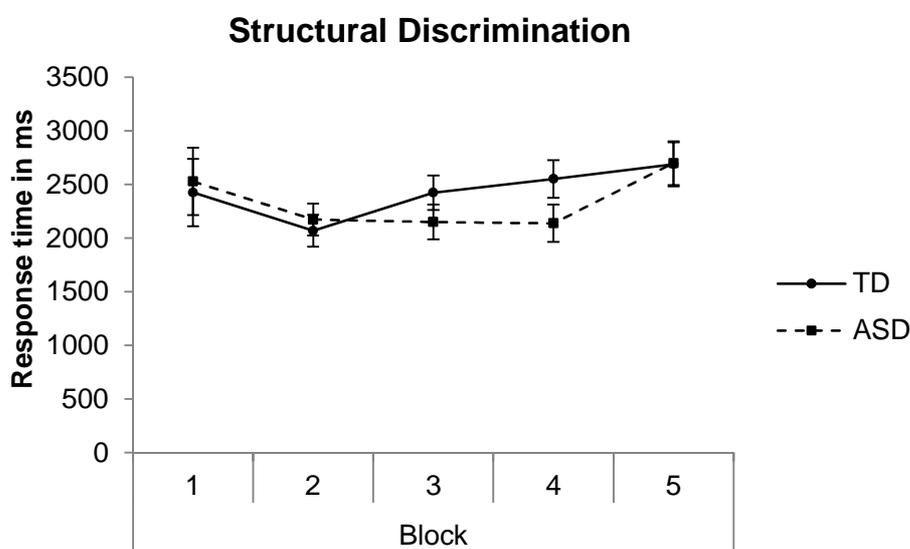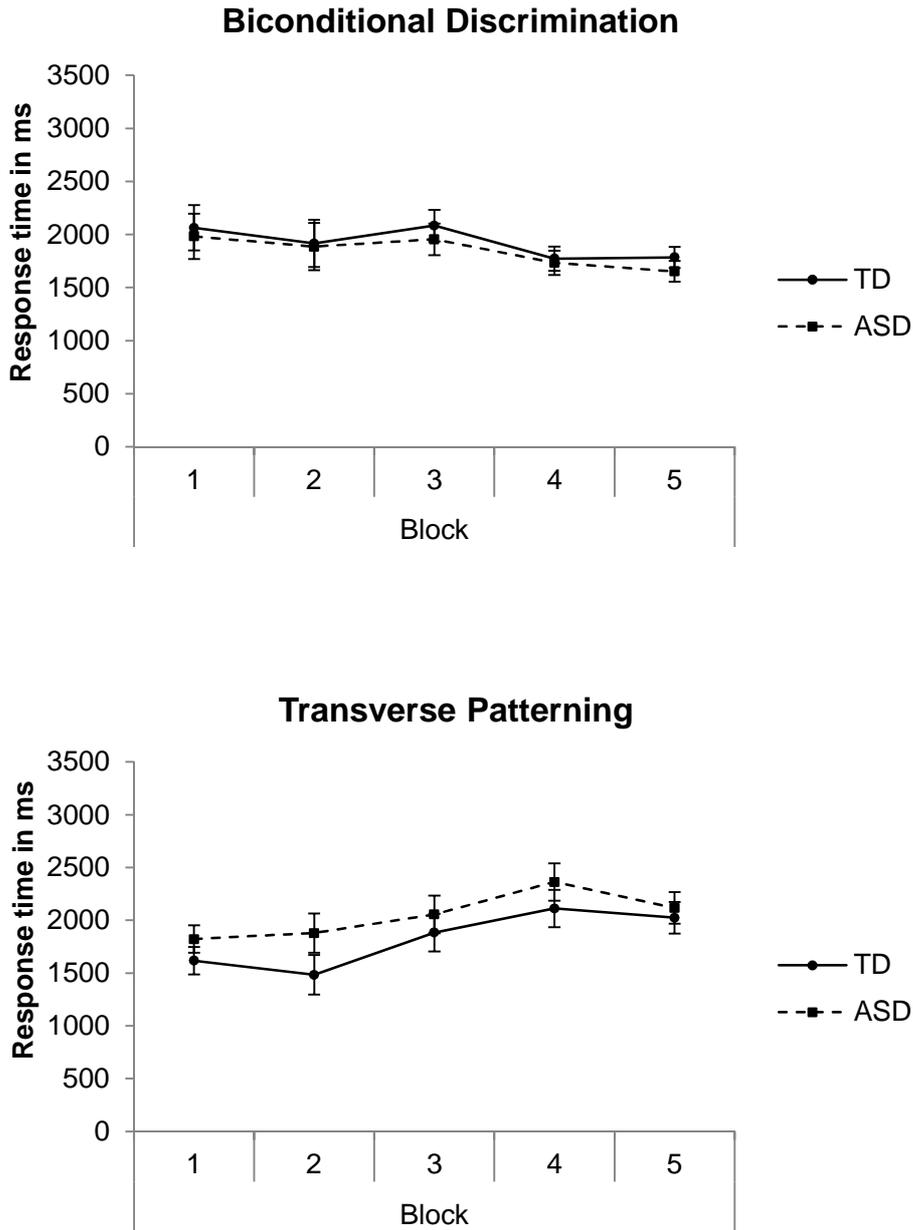
Figure 5.9. Response times in ms for the five blocks of Structural Discrimination (top), Biconditional Discrimination (middle), and Transverse Patterning (bottom) for ASD and TD participants in Experiment 5. The data are presented as mean ± SEM.

5.1.4.2.2.2   Test

Two (Group [ASD, TD]) x 2 (Trial type [studied, probe]) repeated measures ANOVAs comparing response times for studied and probe trials (Figure 5.10) showed significant main effects of *Trial type* for Structural Discrimination, $F(1,36) = 4.91$, $p < .05$, Cohen's $d = 0.11$,

95 % CI(-0.34, 0.56), and Biconditional Discrimination, $F(1,36) = 4.48$, $p < .05$, Cohen's $d = 0.19$, 95 % CI(-0.26, 0.64), with longer response times for probe compared to studied trials. No main effects of Group or Group x Trial type interactions were significant, $F_{max} < 2.19$, $p_{min} > .14$, $\eta_p^2{}_{max} < .06$.
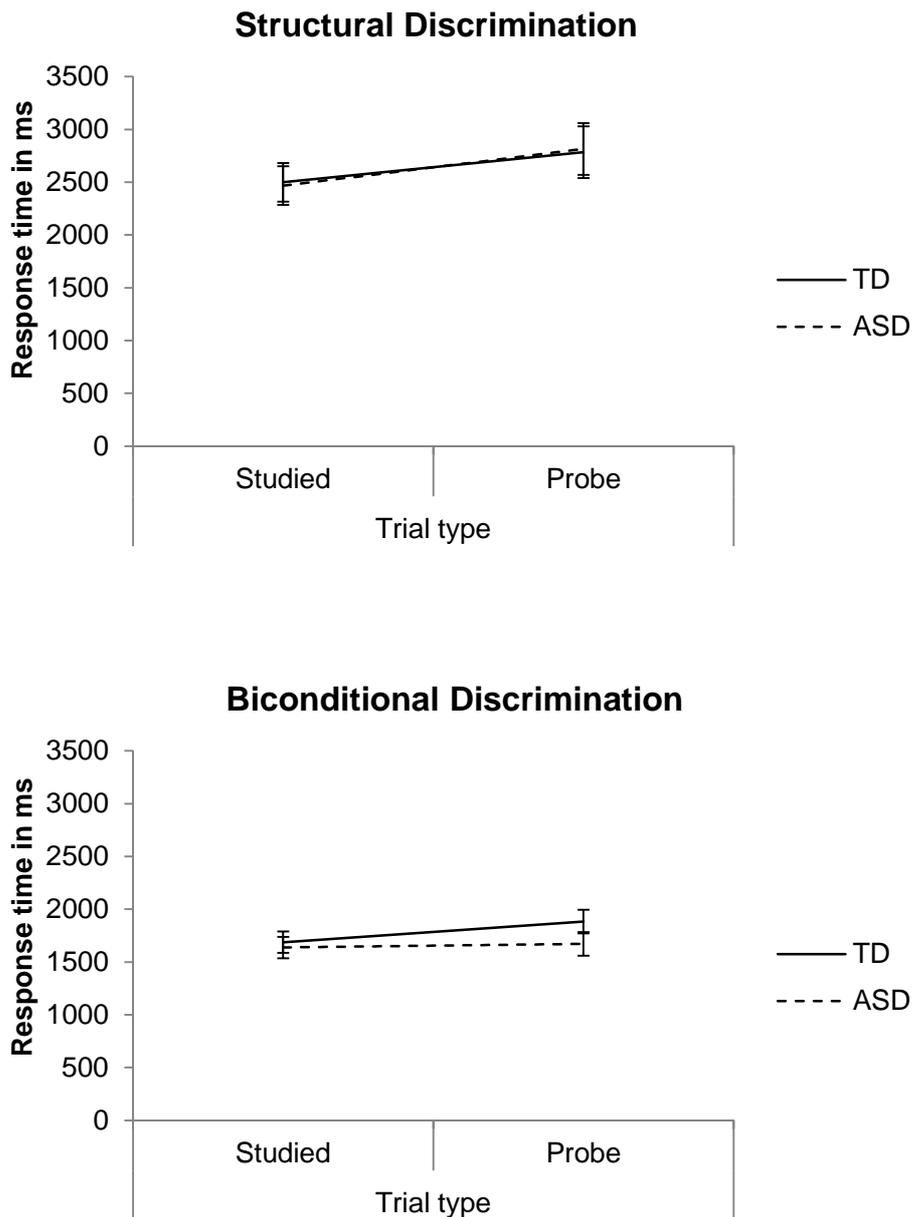
Figure 5.10. Response times in ms for studied and probe trials in Block 5 for Structural (top) and Biconditional Discrimination (bottom) for ASD and TD individuals in Experiment 5. The data are presented as mean ± SEM.

5.1.5 Discussion

The aim of this study was to investigate structural learning as a fundamental mechanism suspected to play a role in the aetiology of ASD. A direct adaptation from the non-human animal learning literature was used to compare structural learning to other forms of configural learning that were well-matched in terms of their processing requirements, and that needed minimal verbal instructions. Although all tasks involved simultaneous discriminations with simple geometric shapes, participants needed to take spatial arrangements into account only in Structural Discrimination. A form of simple learning and a task measuring EFs were included to test response perseveration in the sample recruited.

It was predicted that the ASD group would show lower learning and lower test performance in Block 5 only in Structural Discrimination, with intact performance on Simple and Biconditional Discrimination and Transverse Patterning. Difficulties in Structural Discrimination were expected not to be associated with functional frontal lobe impairments in the ASD group (Sanderson et al., 2006).

Confirming the prediction, ASD compared to matched TD participants showed significantly lower structural learning accuracy, which was not caused by a speed-accuracy trade-off, an impaired ability to discriminate between two simple shapes, or inflexible response patterns, as similar response times, intact performance on Simple Discrimination and the CTT2 suggested. Intact performance for ASD individuals in Biconditional Discrimination and Transverse Patterning suggested that structural learning difficulties were not the result of difficulties with simply binding two elements (Biconditional Discrimination) or alternating rules depending on the context (Transverse patterning), but that they were rather related to the combination of these two processes by additionally taking into account the spatial arrangement of the stimuli and, therefore, suggesting a specific structural learning rather than a more general configural learning deficit in ASD. Paralleling specific Structural Discrimination impairments in rats with hippocampus lesions (Sanderson et al., 2006), the

current result lends further support to accounts of atypical hippocampal functioning in ASD (Section 1.4.2.1; Bowler et al., 2011; Gaigg et al., 2015).

Confirming the second prediction, TD individuals showed complete transfer from studied to probe trials in Block 5 of Structural Discrimination, resulting in similar performance in both conditions. By contrast, ASD individuals showed reduced consideration of the spatial arrangement of the stimuli, resulting in better performance in probe trials compared to studied trials. Similarly, although not apparent in the ratio scores, ASD individuals showed slightly better performance on probe compared to studied trials in Block 5 of the Biconditional task, again suggesting that they did not take into account the spatial arrangement of the stimuli as much as TD individuals did, when performing the task. The somewhat paradoxical superior performance of ASD participants in re-paired as opposed to previously studied images is in line with studies showing reduced transfer of information from one context to another and, therefore, suggested reduced generalisation in ASD (Sections 1.2.5; 1.4.2.5.4). In particular, in a perceptual discrimination task Plaisted et al. (1998a) showed lower performance of ASD individuals on previously trained images and higher discrimination of novel images compared to TD individuals. In the current study, ASD individuals took less into account the structural configuration of the stimuli at study, therefore, showing reduced transfer of this information to test and being less hindered by it, demonstrating superior performance in re-paired images. A bias for local rather than global scene-like processing of the materials (Deruelle et al., 2008; Happé and Frith, 2006; Plaisted, Saksida, Alcántara & Weisblatt, 2003) may have also played a role in these findings. According to this processing style, when trying to remember which images of the current study were correct, TD individuals would have looked at the global form of the image, for example, when remembering that *black/white* was correct as opposed to *white/black*, they would have processed the images as a single image with two parts, with *black* on the left or

the right side of *white*, and they would have remembered that *black* needed to be on the left side of *white* in order for the image to be correct. By contrast, ASD individuals would have focussed on the individual parts of the images, and would have processed the *black* and *white* sides of the images as two separate images, not taking into account the global structure of the image. Therefore, *black/white* and *white/black* would have looked alike to them, making it very difficult for them to discriminate these shapes. This example illustrates how a local rather than global processing style can also explain reduced learning performance in the ASD group on Structural Discrimination. Local processing would have been a disadvantage for the discrimination of mirror images, which was confirmed by the above chance performance of ASD individuals on only two of the three presented discriminations. For these two discriminations ASD participants may have used strategies other than structural learning, such as intact Transverse Patterning, not depending on the hippocampus, and enabling correct answers for about 2/3 of the trials. For example, using Transverse Patterning when presented with *black/white* vs. *white/black*, ASD participants would have ignored one part of the image, by solely looking at the *black* part of one image and the *white* part of the other image, and they would have remembered that, when *black* and *white* were presented, that *black* needed to be left. Via such a strategy, performance on probe trials would have increased to above 2/3 of trials, since they presented previously unpaired images, and seeing a remembered previously non-reinforced image together with a forgotten image, participants would have been able to infer that the correct image should have been the forgotten one. For example, if participants had previously learned that *black/white* rather than *white/black* was correct, and that *striped/black* rather than *black/striped* was correct, participants would have potentially been able to infer that, when they saw *white/striped* vs. *white/black*, that *white/striped* should have been correct because the pair *white/black* was never correct (see Appendix 3 for the stimuli). In addition, following the logic of the WCC theory, probe trials should have been easier for

ASD individuals, since they presented different patterns, such as *black/white* and *striped/white*, and, therefore, the two shapes presented together would have not looked alike to persons with ASD.

The current findings raise a number of questions regarding the role of task support, the number of learning opportunities, and whether ASD individuals would at all be able to acquire structural learning. It is important to note that in the animal literature, which the present paradigm was borrowed from, rodents are normally trained and tested on structural learning over multiple sessions over several days (Sanderson et al., 2006), instead of within a single session over a number of training blocks. Therefore, it would be of interest to examine learning over multiple training sessions in future studies to establish how much more training individuals with ASD may require to achieve levels of performance similar to TD participants, and to establish whether they may or may not acquire structural learning at all, even with repeated training opportunities. It remains also possible that ASD performance may be improved through task support (Bowler et al., 1997; Bowler et al., 2004; Gaigg et al., 2008) in future studies. For example, it should be tested whether instructing and training ASD individuals to use a global rather than a local processing style, may help them acquire structural learning. In this context, findings that show that despite a local preference, ASD participants were still sensitive to the global configuration of images (Plaisted, Dobler, Bell & Davis, 2006; Plaisted et al., 2003; L. Wang et al., 2007), and that training in the use of global processing in ASD has been successful for facial processing (Chabani & Hommel, 2014), seem promising. Also important would be to test whether the current finding of difficulties in spatial structural learning in ASD would extend to the temporal domain (Aggleton et al., 2007), as studies of reduced memory for temporal context in ASD would suggest (see Section 1.4.1.4 and Experiment 3 in Section 3.2). If it were not possible to improve structural learning through environmental support, the current finding would lead to

the conclusion that ASD individuals' difficulties in learning, memory, and more generally in the area of social functioning, may be caused by a specific impairment in a fundamental learning process that necessitates the binding of two pieces of information together with their context (see Bowler et al, 2011; Section 1.4.2.1).

Regarding brain regions underlying structural learning, non-human animal studies emphasize the role of the parietal lobes, in addition to the hippocampus, since rats with hippocampal and parietal lesions showed close to chance Structural Discrimination performance (Aggleton et al., 2007; Sanderson, 2005). Behavioural similarities between ASD individuals and parietal patients (Section 1.4.2.4), the parietal lobes' role in memory (Sections 1.4.1.4, 1.4.2.4) and attention (Section 1.2.7), as well as the finding that Structural Discrimination performance benefitted from good attention shifting skills in both groups in the current study, supported the idea that the parietal lobes may have also played a role in the behavioural differences observed in ASD in the current study.

In conclusion, the current paradigm has the great advantage of being a direct human adaptation of a non-human animal learning paradigm, which not only enables to hypothesise about brain regions underlying difficulties observed in ASD, but which also shows potential utility for testing less verbal individuals. As such, it has the potential to inform us about severely disabled, as well as very young individuals with ASD, who are under-researched populations for which it has proved very difficult to find suitable tests. Overall, the data presented here suggested specific difficulties in structural learning in ASD that likely form the basis of more complex processes like learning, memory, spatial navigation, and the competencies necessary for successful social interactions. They further undermined the idea that ASD is not characterised solely by difficulties in social cognition, but that more domain-general cognitive difficulties are apparent. A discussion of all five experiments, as well as overall conclusions, will be presented in the next chapter.

6 Chapter 6: Discussion

6.1 Summary of empirical findings

The work presented in this thesis comprised a series of five experiments that were aimed at expanding existing behavioural research on memory in ASD by using novel behavioural paradigms designed to shed further light on the integrity of relational and item memory processes. The current thesis also aimed to extend the existing literature on memory for verbal material to the domains of visual perceptual materials and spatial navigation. In addition, by drawing on eye-tracking technology and experimental paradigms informed by the animal literature, this thesis aimed to develop methods that would be useful in future studies to examine memory in younger and/or less able individuals with ASD, who remained under-researched so far. The results were used to refine models of cognitive functioning in ASD, to shed light on the possible neural underpinnings of memory difficulties in this disorder, and to explore the role that age may play in the memory profile of adults with ASD. Overall, 169 ASD participants (138 men) with a mean age of 43 years (SD_{age} = 12.5) and VIQ, PIQ, and FIQs within the average range (M_{VIQ} = 111, SD_{VIQ} = 16.0; M_{PIQ} = 106, SD_{PIQ} = 16.2; M_{FIQ} = 109, SD_{FIQ} = 15.9) were tested. Their performance was compared to that of 161 TD adults (123 men) with a mean age of 42 years (SD_{age} = 12.9) and average VIQ, PIQ, and FIQs (M_{VIQ} = 112, SD_{VIQ} = 13.8; M_{PIQ} = 107, SD_{PIQ} = 14.1; M_{FIQ} = 110, SD_{FIQ} = 14.1). To serve as an *aide mémoire* to the reader, an overview of all studies and their main results is presented in Table 6.1.

Table 6.1

Summary of the main findings from Experiments 1 - 5.

Participants and characteristics			Materials and procedures	Results	Conclusions	Questions and research directions raised by studies
Recognition memory in adults with Autism Spectrum Disorder – the pupil Old/New effect						
	ASD	**TD**	Words, pictures, non-words, abstract shapes	**Behavioural accuracy** Visual > verbal	**Behaviour** Picture superiority in ASD.	Would memory for objective context also be reduced in ASD individuals?
N	32	32				
men	27	25				
age (yr)	44	44	**Behaviour**	Meaningful > meaningless	Advantage for use of meaning inherent in stimuli.	
VIQ	111	112	Yes/No and			Systematic investigations
PIQ	105	105	R/K recognition	R > K	Better memory for context of item.	needed testing relational
FIQ	110	109	tests			memory (memory for objective context) using visual materials.
			R justifications	TD > ASD in corrected recognition, TD > ASD in R responses	Reduced recognition in ASD related to reduced EM for subjective context (R responses, retrieval of relational material) in ASD.	
				TD > ASD in R justifications, TD > ASD in information from outside study episode	Reduced generalisation in ASD.	
				FA: ASD > TD Sensitivity: TD > ASD	Difficulties to distinguish old and new material in ASD.	
				A' recognition > A' R	Support for dual process model.	

Participants and characteristics			Materials and procedures	Results	Conclusions	Questions and research directions raised by studies
				Age better predictor for R responses in TD.	Stronger age-related difference in R responses in TD vs. ASD.	What would be the influence of age on relational memory in ASD?
			Pupil size Pupil Old/New effect	**Pupil size** Verbal > visual Meaningful > meaningless	**Pupil size** Pupil size sensitive measure - replication of behavioural results.	
				TD: old > new ASD: old = new	Different physiology in recognition memory in ASD. Potential biomarker for ASD.	
				Correlation between behavioural accuracy and pupil Old/New effect.	Pupil Old/New effect reflected real memory phenomenon.	
Explicit and implicit relational memory for object-locations in adults with Autism Spectrum Disorder						
	ASD	**TD**	Pictures of objects and scenes	**Behavioural accuracy** TD > ASD for old location (Include) TD = ASD for new location (Exclude)	**Behaviour** Difficulties with memory for locations in ASD.	Would other relations such as temporal order or set also be difficult for ASD individuals?
N	25	23				
men	20	17				
age (yr)	42	41	Locations for objects in scenes			
VIQ	108	114				What was the influence of language on memory when using pictures of daily objects? Would it be reduced by using abstract shape images?
PIQ	106	109	**Behaviour** Include/exclude recognition test	TD > ASD in explicit memory TD = ASD in implicit memory	Intact implicit but impaired explicit relational memory in ASD.	
FIQ	108	113				

Participants and characteristics				Materials and procedures	Results	Conclusions	Questions and research directions raised by studies
				Explicit and implicit memory	**Behavioural accuracy** Age better predictor for explicit memory in ASD.	Stronger age-related explicit memory difference in ASD vs. TD, contrary to Exp. 1.	What would be the influence of age on other memory types in ASD?
				Yes/No Recognition and source memory tests	No between-group differences in item and source memory.	With task support, intentional encoding, and one type of context item and source memory intact in ASD.	Would item memory still be intact when using tasks of similar complexity as relational memory tasks?
				Eye movements Encoding Areas on the screen attended to (Scene, object, object-location in scene)	**Eye movements Encoding Fixation duration** Scene > Location > Object Behaviourally incorrect trials: TD > ASD on Scene and Location	**Eye movements Encoding** Scene context most attended to. Differences between groups in attentional focus at encoding.	Systematic comparisons of item memory and memory for different kinds of relations needed.
				Retrieval Average fixation duration on Target (original object location) and Distracter locations (new object locations)	Correlations between implicit memory and fixation duration on Scene. **Retrieval** Include > Exclude Target > Distracter	Reduced attention to context at encoding and, therefore, reduced relational binding as a contributor to memory difficulties in ASD. **Retrieval** Main effects and interactions in eye-movement retrieval data indicated it as a sensitive measure.	Would reduced attention to context also be found in other situations such as spatial navigation?

Participants and characteristics				Materials and procedures	Results	Conclusions	Questions and research directions raised by studies
					Retrieval Target Include > Distracter Include Distracter Exclude > Target Exclude		
					TD > ASD Target Include and Distracter Exclude	Retrieval eye-movement data reflected difficulties in explicit and implicit relational memory.	
					No differences in fixation duration for unstudied objects.	Differences unlikely to have been related to instruction or intention to select a certain location.	
					Fixations on target > distracter related to behavioural target choices.	Eye-movement effects at retrieval reflected real memory phenomenon.	
Relational memory for order, location, and set information across the mid-adult lifespan in persons with Autism Spectrum Disorder							
	ASD	**TD**		Abstract shapes	**Behavioural accuracy**		
N	18	18			TD > ASD in corrected	Item memory difficult in ASD,	What would be the role of item
men	14	13		**Behaviour**	recognition for item and	when tasks had similar complexity	memory in spatial navigation?
age (yr)	43	43		Old/New recognition test	relational tasks	as relational tasks. Item memory difficult, when tasks probed	
VIQ	109	111			ASD at chance in order and	relational processing, replicated	
PIQ	104	105			associative tasks.	findings from Exp. 1.	
FIQ	108	109					

Participants and characteristics				Materials and procedures	Results	Conclusions	Questions and research directions raised by studies
					Behavioural accuracy Large effect sizes for between-group differences in all tasks.	Different kinds of relations seemed similarly difficult in ASD. Difficulty in location memory in ASD replicated findings from Exp. 2.	How well would ASD participants perform when relational memory for location was needed in a more applied context such as spatial navigation?
					FA: ASD > TD Sensitivity: TD > ASD	Replication of Exp. 1 showing difficulties to distinguish old and new materials in ASD.	Systematic investigations of different kinds of spatial navigation needed, examining the role of complexity by manipulating demands on EFs.
					TD: correlations between item and relational tasks and among all relational tasks	Correlations may have indicated flexibility in using relational processing in all tasks among TDs.	
					ASD: only few significant correlations among relational tasks	Lack of correlations among tasks may have indicated inflexibility in using relational processing in ASD or difficulties with EFs. ASD individuals may have approached each task differently.	
					Younger and older ASDs performed similarly to older TDs in order task.	Order memory more affected by age in TD individuals – replicated Exp. 1, contrary to Exp. 2.	What would be the effect of age on spatial navigation in ASD?

Participants and characteristics			Materials and procedures	Results	Conclusions	Questions and research directions raised by studies
Spatial navigation from same and different directions: The roles of executive functions, memory, and attention in adults with Autism Spectrum Disorder						
	ASD	**TD**	Video of a route through a maze, static images of intersections	**Behavioural accuracy** Same > different direction trials	Better performance in egocentric vs allocentric navigation.	Would more fundamental learning processes be affected in ASD?
N	37	31				
men	30	25				
age (yr)	43	41		Increase in performance across blocks.	Learning across blocks.	
VIQ	111	115	**Behaviour**			
PIQ	107	110	Learning over			
FIQ	110	114	six blocks	TD > ASD	General navigation deficit in ASD independent of condition, when conditions were matched on complexity.	
			Three possibility forced choice test			
			Free and cued recall tasks	Different-same > same-different direction switch	Switch to an allocentric strategy was more difficult.	
			Test of EFs	TD > ASD in switch performance	Difficulties in switching between conditions in ASD may have contributed to navigation deficit.	
				No group differences in strategy use.	Both groups used similar strategies for the task.	

Participants and characteristics	Materials and procedures	Results	Conclusions	Questions and research directions raised by studies
		Behavioural accuracy ASD > TD in perseverative errors TD > ASD in free and cued recall for items and item positions Perseverative errors predicted egocentric navigation. Age better predictor for egocentric navigation performance in ASD. Perseverative errors and item task performance predicted allocentric navigation. Age better predictor for allocentric navigation in TD.	Difficulties in EFs in ASD. Item memory difficulties in ASD for incidentally encoded materials. Difficulties in egocentric navigation and stronger age-related egocentric navigation difference in ASD may have been related to task demands on EFs. Item memory and EF difficulties contributed to navigation difficulties in ASD. Stronger age-related allocentric navigation difference in TD vs. ASD - replicated Exp. 1 and 3, contrary to Exp. 2.	A systematic investigation of different learning processes in ASD would be needed, as well as a test of how they would be affected by EFs.

Participants and characteristics	Materials and procedures	Results	Conclusions	Questions and research directions raised by studies
	Eye movements Average fixation duration and number of fixations	**Eye movements** **Encoding** Back > front item		
		TD > ASD	ASD individuals attended less to the landmarks at encoding - replicated findings of Exp. 2 of reduced attention to context in ASD.	
	Measuring attention to items marking the intersections	Back > front animal related to egocentric navigation in TDs.	Attention at encoding related to later egocentric navigation.	
	Encoding and Retrieval	**Retrieval** Front > back item		
		Same = different for ASD	Possible indication of difficulties to distinguish old and new images in ASD - replication of Exp. 1 and 3.	
		Different > same direction for TDs only		
		Front > back animal related to allocentric navigation in ASD.	Attention at retrieval indicated reduced EM in ASD.	

Participants and characteristics			Materials and procedures	Results	Conclusions	Questions and research directions raised by studies
Structural and configural learning in adults with Autism Spectrum Disorder						
	ASD	**TD**	Pictures of geometrical patterns	**Behavioural accuracy** **Structural task**		
N	57	57				
men	47	43		Decrease followed by increase in performance	Increasing task difficulty and learning across blocks.	Would more learning opportunities or task support be helpful to improve structural learning performance in ASD, and would they help with the acquisition of structural learning?
age (yr)	43	42				
			Behaviour			
VIQ	112	110	two alternative forced choice tests	TD > ASD in learning and test phase	Indication of difficulties in binding information to context in ASD.	
PIQ	106	105				
FIQ	109	108		ASD > chance on two discriminations	ASD group did not acquire structural learning, use of simpler forms of learning.	
			Test of EFs			
						Would there also be a structural learning deficit in ASD in a temporal context or would persons with ASD show specific difficulties related to spatial material?
				ASD: probe > studied (structural and biconditional)	ASD less hindered by previous learning of structural relations of images. Hints at local processing and reduced transfer in ASD.	
				Ratio scores: ASD > TD, larger difference between probe and studied trials in ASD	TDs showed transfer from studied to probe trials.	What would the results look like in less verbal and/or less intellectually able ASD individuals?
				No between-group differences in response times, Simple Discrimination, EFs, Biconditional Discrimination, and Transverse Patterning.	Structural learning difficulties in ASD not caused by speed-accuracy trade-off, EFs, difficulties discriminating between two simple shapes, or simpler forms of binding or rule alternation.	

Experiment 1 aimed to replicate and extend studies on recognition memory in ASD by using the R/K procedure with verbal, visual, meaningful, and meaningless materials, and pupil size measurements were taken to learn about the underlying physiology of recognition memory in ASD. In addition, the study aimed to examine the usefulness of pupil size measurements for testing memory in ASD with a view to evaluating their potential for the use in younger and less verbal and/or intellectually able ASD individuals. Finally, it was of interest to investigate the effect of age on R responses in ASD and TD participants. Behaviourally, previous results were replicated and extended in showing reduced EM but intact SM in ASD for all tested materials. Both participant groups showed superior memory for pictures and meaningful materials and higher R compared to K responses. In addition, ASD memory was characterised by higher FA rates and lower sensitivity that indicated difficulties to distinguish old and new materials. ASD individuals showed lower recognition memory that was, primarily, related to lower levels of R but not K responses, supporting theories suggesting difficulties in relational processing in ASD. In particular, when looking at R justifications, whereas TD individuals related material from the current study episode to previous experiences, ASD individuals relied mostly on the information provided in the study materials and, therefore, showed reduced use of meaning and transfer of information across study episodes. More generally, the behavioural data found support for a two-process model of recognition memory rather than one represented by one process with different levels of strength. Pupil size measurements replicated the behavioural memory data in that differences were found between meaningful and meaningless materials for both groups. The absence of a pupil Old/New effect in ASD suggested a recognition memory impairment, showing that on a physiological level, ASD individuals did not distinguish between studied and unstudied items to the same extent as TD participants did. Reduced pupil sizes for old items in ASD may have been an indicator of cognitive overload during the task leading to reduced task engagement

and a "levelling" of the pupil size (Granholm et al., 1997; Van Gerven et al. 2004), or of reduced memory strength in ASD (Papesh et al., 2012), leading to difficulties in distinguishing studied from unstudied materials at retrieval. The lack of the pupil Old/New effect in ASD taken together with reduced emotional responsiveness found with pupil size measurements in ASD (Nuske et al., 2014b & c), suggested a general cognitive deficit rather than a pure social impairment in ASD. Typical pupil responses in ASD at baseline made a general abnormality of pupil physiology in ASD an unlikely cause of the results. Significant positive correlations between behavioural recognition accuracy and the pupil size Old/New difference suggested that the pupil Old/New effect reflected a real memory phenomenon, and that pupil size measurements would be of potential use for the measurement of recognition memory in less verbal and/or intellectually able individuals with ASD. Further, because of the differences between pupil size abnormalities in ASD and those found in other disorders (Laeng et al., 2007), and because of the known underlying neurochemical pathways for pupil size effects (Goldinger & Papesh, 2012; Hoffing & Seitz, 2015), the absence of a pupil size Old/New effect was suggested as a candidate for a unique biomarker for ASD. Finally, a larger age-related difference in R responses in the TD as opposed to the ASD group supported the safeguard hypothesis (Geurts & Vissers, 2012), suggesting that older ASD individuals may be less affected by cognitive decline. To conclude, next to the establishment of the pupil Old/New effect as an innovative way to measure recognition memory in ASD, and the finding that recognition memory difficulties in ASD were related to reduced relational processing, one of the current studies' novel contributions was the finding that ASD individuals showed particular difficulties in relating details from the current episode to knowledge and experiences from outside the immediate study context. Given these findings, it was important to look more closely at within-experiment relational information, and in this context spatial-contextual information was of interest.

After having established an EM deficit in ASD that seemed to be related to the processing of relational information, and having found that picture memory was superior to memory for words in both groups, Experiment 2 aimed to examine memory for relational material more directly in ASD by using an everyday relational memory task with pictures as materials. The task was designed to investigate explicit and implicit memory asking whether implicit memory would still be intact for relational material in ASD. A second aim was to validate the behavioural results, and to investigate attention, through the use of eye-movement measures. Finally, item memory was also measured, and the effect of age on explicit memory was examined in both groups. An include/exclude recognition memory procedure was used to calculate estimates of implicit and explicit memory for object-location combinations. Behaviourally, ASD individuals showed lower explicit relational memory as opposed to TD participants. No between-group differences were found in implicit relational memory. Eye-movement measures at retrieval, however, showed reduced fixation durations in ASD to locations that participants were asked to choose, indicating differences in the allocation of attention during retrieval of spatial relational information in ASD. Positive correlations between fixations on previously studied, as opposed to new locations, and behavioural choices of these locations indicated that these attention differences at retrieval reflected a real memory phenomenon. Therefore, reduced fixation durations on previously studied locations in ASD in the current study pointed to difficulties in implicit relational memory. In addition, the eye-movement encoding data for later incorrectly remembered material indicated less attention to context information and information that needed to be studied, i.e., location information, in ASD, and correlations showed that, in particular, attention to context information at encoding was related to later implicit relational memory, highlighting the role of attention allocation and relational processing at encoding for subsequent memory. An analysis of the influence of age on explicit relational memory in both groups showed that

ASD was related to a larger age-related memory difference in explicit relational memory, which was contrary to the finding of Experiment 1 of a reduced age-related memory difference in R responses in the ASD group, and which highlighted the need for further investigations on this topic, as larger memory differences in ASD with age would have important implications for care provisions. Finally, item memory was found to be intact in ASD in this study. Contrary to Experiment 1, where recognition memory strongly relied on Remembering, item memory tasks in the current study may have benefitted more from intact Knowing in ASD and, in addition, a supported test was used for material that had been studied intentionally, therefore, creating a potentially easier test for ASD individuals. To conclude, through the use of eye-movement measures a deficit in implicit relational memory in ASD was discovered, and it was found that attention patterns at encoding may have contributed to memory difficulties in ASD found at retrieval. In addition to pupil size, fixation duration was indicated to be a fruitful measure to use in memory test adaptations for less verbal and/or intellectually able ASD individuals.

Having established that relational memory for location information was difficult for ASD individuals in Experiment 2, the aim of Experiment 3 was to systematically investigate relational memory for location information in comparison to other kinds of relational as well as item information. By using abstract shape images, the influence of language and previous experience with materials on memory was reduced, which was important as these factors may have differed between groups. Experiment 3 also aimed to test the idea that some item memory tests are particularly difficult for ASD individuals because they probe relational processing, by matching item and relational memory tasks on complexity. Finally, the effect of age on relational memory was examined in both groups. Memory was tested by means of a recognition test procedure presenting three items at a time, manipulating item, location, order,

or set information. Overall, ASD compared to TD participants performed worse on all tasks and, replicating findings from Experiment 1, lower task performance was related to difficulties in distinguishing old and new materials, as indicated by higher FAs and lower sensitivity in the ASD group. Also replicating Experiment 1, the data supported a two-process model of recognition memory best. Large effect sizes for the between-group differences on all tasks indicated similar difficulties in all kinds of tested relations in ASD and, thereby, replicating and extending findings from Experiment 2 with a different paradigm and different materials. Difficulties in item memory replicated findings from Experiment 1, and overall both experiments showed that difficulties in remembering single items may emerge, when such memory relies on relational information, i.e., the relations between items or relations among items and their context). In line with Experiment 1, but contrary to Experiment 2, age had a more pronounced effect on order memory in the TD, but not the ASD group, in the current study. This may be the case because younger ASD individuals already performed at the level of TD OA in this study, but the inconsistencies in the findings between the studies of this thesis also reflected the need for more research in this important area. Correlations among item and relational memory tasks in the TD group indicated that TD participants may have used relational processing flexibly to support their task performance, whereas the absence of such correlations in persons with ASD may have indicated inflexibility in the use of relational processing or difficulties in EFs that may have influenced their memory performance. To conclude, item memory has been found difficult for ASD individuals, when it was measured with tasks of similar complexity to relational memory tasks, which made stronger demands on relational processes. Different kinds of relational memory have been of comparable difficulty for ASD individuals, and reduced relational processing, i.e., reduced binding of item and context information, may have been responsible for this deficit.

Following on from the difficulties in relational memory in ASD found in the previous three experiments, the aim of Experiment 4 was to investigate relational processing and memory for location information in the more applied area of spatial navigation, measuring the roles of complexity, EFs, attention, and item memory in this context. In addition, the influence of age on spatial navigation was examined in both groups. Experiment 3 highlighted the importance of complexity, by revealing difficulties in item memory in ASD, when procedures for item and relational memory were matched on complexity, and it hinted at the importance of EFs for memory in ASD, by showing inflexibility in the use of relational processing. Experiment 2 demonstrated that reduced attention to context details in ASD may have contributed to later difficulties in memory retrieval. Finally, memory for items was considered important, because spatial navigation and memory were found to be related processes depending on similar brain regions (Burgess et al., 2002), and because successful spatial navigation depended on item cues (Bohbot et al., 2004). Different types of spatial navigation were compared within the same task asking participants to learn a route over six blocks, by presenting a video of a maze, including intersections with navigation cues. ASD, as opposed to TD participants, performed worse in both conditions, confirming difficulties with location material found in Experiments 2 and 3. In addition, the importance of complexity found for memory in Experiment 3 was also highlighted for spatial navigation. Lower navigation performance in ASD may have been related to difficulties in distinguishing old from new materials, as indicated by similar fixation durations on studied and new images of the intersections presented at test in ASD, as opposed to TD participants, replicating findings from Experiment 1 and 3. Navigation difficulties in ASD in the current study were also related to the demands of the navigation task on EFs, as indicated by poorer EFs in ASD in the current study, the role of EFs in predicting navigation performance, and their possible relation to a greater age-related egocentric navigation difference in ASD, as opposed to TD

participants, in the current study. In addition to EFs, navigation difficulties were also related to lower memory for the items marking the intersections and to reduced fixations on these items at encoding. These observations replicated findings from Experiment 2, indicating the role of a different attention allocation for memory in ASD. Eye-movement differences at retrieval pointed to reduced relational binding of items to context in ASD and, together with findings from Experiments 1 and 2, indicated the usefulness of eye-movement measurements for uncovering the memory difficulties in ASD with measures outside conscious awareness. Finally, contrary to findings from Experiment 2, but in line with Experiments 1 and 3, larger age-related differences in allocentric navigation were found for TD compared to ASD individuals. Therefore, most studies of this thesis supported the safeguard hypothesis, suggesting that ASD adults with average and above average intellectual functions may be less affected by age-related cognitive decline. However, it is important to keep in mind that the current thesis used cross-sectional designs, expressing the need for more systematic longitudinal investigations of the effects of age on memory and related processes in ASD in broader populations with varying intellectual abilities to resolve inconsistencies in the findings. To conclude, Experiment 4 found a general navigation deficit in ASD by using procedures matched for complexity. The deficit was related to reduced item memory and difficulties in EFs.

Following on from Experiment 4, which used a learning procedure and found reduced spatial navigation accuracy in ASD at test, the aim of Experiment 5 was to investigate configural and, more specifically, structural learning as a fundamental learning process that may be responsible for the difficulties observed in relational binding in memory and spatial navigation in ASD. Experiments 2, 3, and 4 showed difficulties with relational memory for location information in ASD, which may have been indicative of particular difficulties with

structural learning, i.e., difficulties that would occur when the structural arrangement of the stimulus array needed to be taken into account in addition to the binding of the two elements. To test this idea, three configural learning tests were used, each simultaneously presenting two images on the screen. Drawing on a paradigm from the non-human animal learning literature, the test of structural learning used a non-verbal method to measure pure hippocampal functioning, which was of interest in the context of the aim to devise a paradigm of potential use for testing a wide range of ASD individuals with varying verbal and intellectual abilities, and when considering memory theories in ASD suspecting atypical hippocampal functioning at the core of cognitive differences in ASD. Experiment 5 found a specific structural learning deficit in ASD, which was not caused by a speed-accuracy trade-off, inflexible response patterns, executive dysfunction, difficulties in simply discriminating or binding two items, or problems related to contextual rule alternation. To conclude, the findings of this study suggested a fundamental learning process - such as structural learning – to be impaired in ASD, which may form the basis for the cognitive difficulties observed in areas such as (relational) memory and spatial navigation in this population.

Following the overview of the findings of this thesis, the results will now be discussed in relation to the topics presented in the introduction at increasingly broader levels.

6.2   Conclusions

Despite the limitations on the studies that have been discussed at length during the presentation of each of the individual experiments, the present chapter will discuss wider issues and implications of the findings. The results will first be considered in relation to previous findings on memory in ASD, then they will be set in relation to theories about memory and cognitive functions in ASD, and the chapter will finish with conclusions about ASD as a disorder.

6.2.1 Conclusions for memory findings in ASD

With reference to the empirical findings on memory in ASD presented in Section 1.4.1, previous findings were replicated. Experiment 1 found support for reduced EM and intact SM in ASD (Section 1.4.1.2) by using a R/K recognition paradigm, which showed fewer R responses for ASD as opposed to TD individuals. This result was found for verbal and visual and meaningful and meaningless materials, which generalised findings on memory in ASD across different materials. Reduced EM in ASD was also found in Experiments 2 and 3. Experiments 1, 3, and 4 suggested that these EM difficulties were related to particular difficulties in distinguishing between previously studied/old and new materials. Regarding the factors affecting EM in ASD (Section 1.4.1.3), Experiment 2 found fewer memory difficulties in ASD, when using a supported item memory test procedure, and Experiment 4 found that ASD individuals used supporting information inherent in the study materials less than TD participants, in that they attended less to navigational cues at study. Difficulties in establishing meaning in ASD were found through R justifications in Experiment 1 that were focussed on the current study episode, and that did not generalise across different episodes of experience. Experiments 2 and 3 both confirmed previous findings of difficulties with relational materials in ASD (Section 1.4.1.4) by using behavioural and physiological measures, and by finding that different types of relations, i.e., location, temporal order, and set, were similarly difficult for ASD participants. These findings replicated those of earlier studies.

In addition to replicating existing findings, the experiments reported in this thesis extended previous research. Experiment 1 illustrated that under conditions, where recognition memory relied heavily on Remembering, and, therefore, the retrieval of context information, overall recognition memory for single items was impaired in ASD, resolving some inconsistencies in the previous literature. Experiment 3 confirmed these findings by revealing difficulties in item memory in ASD in test procedures that relied strongly on relational

processing. One possible reason for the R deficit found in Experiment 1 was that, in particular, ASD individuals related the current study episode less to prior knowledge and experiences, supporting ideas about reduced transfer of information in ASD across study episodes (Section 1.2.5). In a more general context, reduced transfer may help to explain why people with ASD have difficulties adapting flexibly to novel situations and react anxiously in similar, re-occurring situations that ought to be familiar to them. Experiment 4 also helped to resolve some inconsistencies in the previous literature by showing that, even when conditions were matched on complexity, spatial navigation remained an area of difficulty in ASD. The use of pupillometry and eye-movement measures to investigate memory processes in the current thesis has been very fruitful. Regarding pupil size measurements, it was possible to extend previous literature by showing that pupil size at baseline in ASD adults did not differ from that found in TD adults (in Experiment 1), which was unlike previous findings showing larger baseline pupil sizes in ASD children. These data together with the children data from previous studies (C. J. Anderson & Colombo, 2009; Blaser et al., 2014) suggested developmental trends in changes of pupil size over time, which should be investigated in future research. Experiment 1 showed a different underlying physiology for recognition memory in ASD with pupil size measures replicating previous findings gathered through the use of ERPs. In addition, eye-movement measurements in Experiment 2 have helped to draw connections between the distinctions of item and relational, and implicit and explicit memory by showing that implicit memory for relational material was impaired in ASD, when tested with physiological measures, suggesting specific difficulties in relational processing rather than difficulties with explicit memory in ASD. The correlations between behavioural memory data and the pupil Old/New difference in Experiment 1, as well as the relations found between behavioural memory data and eye-movements in Experiment 2, demonstrated the utility of pupil size and eye-movement recordings as unconscious measures of memory that

would, in principle, be suitable for the use in wider ASD populations. Similarly, a paradigm was created for Experiment 5 that would be suitable to test structural learning in broader ASD samples with varying cognitive and language abilities. The data from Experiment 5 suggested that atypicalities in a fundamental learning process may underlie the cognitive difficulties observed in ASD. The experiments of this thesis also added insight on how age may affect memory in ASD individuals by capitalising on the wide age-range of the samples studied to enable cross-sectional comparisons. Experiment 2 showed that explicit relational memory for location information was more affected by age in ASD as opposed to TD individuals. Specifically, the older individuals in the ASD sample showed particular difficulties with the task. In Experiments 1, 3, and 4, larger age-related memory differences were found for TD as opposed to ASD individuals. It is worth noting that in these three studies, younger ASD individuals already performed at a much lower level as opposed to younger TD individuals, whereas in Experiment 2 younger individuals in both groups performed almost similarly. Processes related to age-related memory changes in TD individuals may operate at an earlier age in some ASD individuals, in others they may operate more strongly leading to a greater decrease in cognitive function in ASD as opposed to TD with age. It should be borne in mind, however, that the findings reported in this thesis may have been compromised by a sampling bias in that self-selected samples of intellectually able (older) ASD individuals were tested and the results may, therefore, not be representative for all older ASD individuals. Finally, the studies of this thesis have highlighted the influence of other processes such as attention and EFs on memory in ASD, and they have shown how these processes are intertwined, which should be considered more in future research.

6.2.2 Conclusions for memory theories in ASD

The findings will now be considered in relation to previously presented memory (Section 1.4.2) and cognitive (Sections 1.2, 1.4.2.5) theories in ASD. Some of the memory theories draw parallels to certain patient groups. It is, however, worth noting that this thesis did not include direct comparisons between ASD individuals and patients with other disorders. In addition, whereas ASD exists from birth onwards and influences the development of the whole individual, in most patient groups, disorders were acquired in later life. Analogies will, therefore, only be simplifications and not sufficient to explain the complexities of the complete profile of strengths and difficulties observed in ASD.

6.2.2.1 Amnesia parallel, hippocampal patients and relational binding account

Supporting and contradictory findings relating to the three accounts presented in Section 1.4.2.1 will be discussed, starting with the amnesia parallel, followed by findings from hippocampal patients, and concluding with the relational binding account. Regarding the amnesia parallel, higher FA rates for ASD compared to TD individuals in the recognition memory tasks used in Experiments 1 and 3 indicated confabulation, which is known from the amnesia literature (e.g., Schnider, Gutbrod, Hess & Schroth, 1996). Another similarity between ASD and amnesia was the eye-movement finding for the retrieval data from Experiment 2. Relational memory in amnesia has been characterised by the absence of a relational manipulation effect in eye movements (Hannula et al., 2007; Ryan et al., 2000), indicating that amnesics were not aware of changes in relational information in the presented material. Similarly, in Experiment 2 ASD individuals showed fewer fixations to the object-location relations tested for a correct behavioural answer. Like in amnesia, eye-movement data indicated specific difficulties with relational information that also affected implicit memory. However, when using paradigms in ASD that have been used in amnesia

previously, results were mostly qualitatively different for ASD individuals. Using a paradigm similar to the one used in Experiment 3, amnesics have been found to perform at chance on the item as well as all relational memory tasks (Konkel et al., 2008). By contrast, in Experiment 3, ASD individuals performed at chance only on two of the three relational tasks, namely the tasks for temporal order and set of item presentation, indicating that the difficulties observed in ASD were much less severe than those known from amnesia. Finally, when measuring pupil size in response to old and new items, individuals with amnesia were found to show a novelty preference. As opposed to TD individuals, whose pupils were larger in response to previously studied compared to unstudied items, amnesics showed larger pupils for new compared to old items (Laeng et al., 2007). Contrary to this, in Experiment 1, ASD individuals showed an absence of the pupil Old/New effect with similar pupil sizes for old and new items. Considering what is known about the underlying neurochemistry of pupil size changes from TD populations (Goldinger & Papesh, 2012; Hoffing & Seitz, 2015), the difference between pupil size effects in ASD and amnesia, indicated the potential of the absence of the pupil Old/New effect as a candidate biomarker that may be specific for ASD.

More similarities were found between findings on memory in ASD and memory in patients with hippocampal lesions. In addition, results from studies investigating memory in non-human animals with a lesion in the hippocampus were considered. Again looking at the paradigm used in Experiment 3, individuals with hippocampal lesions have been found to perform worse on item and relational tasks compared to the control group. However, relational tasks seemed to be somewhat harder for them in that all patients performed at chance on these tasks. Similarly, in Experiment 3, ASD individuals showed difficulty with item and relational tasks. However, they only performed at chance on two of the three relational tasks, with performance on the location and the item task being well above chance. Next to a different neurological origin of memory difficulties in ASD and hippocampal

patients, it is also possible that some alternations in the paradigm may have led to differences in the results. For example, as opposed to Konkel et al. (2008), Experiment 3 of this thesis used fewer study trials per block and one instead of two study opportunities for each item set. Either of those may have had a differential effect on item and relational memory. Whereas longer study blocks may have had detrimental effects on relational memory, in that hippocampal patients got increasingly confused about the relations of the study materials, repetition of study materials may have benefitted item memory more than relational memory (A. Konkel, personal communication, August 31, 2016). Only a direct comparison between ASD individuals' and hippocampal patients' memory within the same study would test these possibilities. When using a direct adaptation of a paradigm from the animal learning literature on which rats with hippocampal lesions had shown particular difficulties in structural learning but not in other configural learning tasks, findings from ASD adults were consistent with hippocampal dysfunction in that task difficulties were restricted to structural learning. However, whereas rats had acquired structural learning, ASD participants appeared to have used some other strategy rather than structural learning to solve the Structural Discrimination task. Also in this study, the methodologies of testing may have been of relevance. In Experiment 5, all participants took part in a single session. Rats, however, had been trained and tested over multiple testing sessions on separate days. A comparison of ASD and TD adults' structural learning performance via multiple testing sessions would be of interest in this context.

Finally, the relational binding account was supported by difficulties in different types of relational memory in ASD, i.e., location, temporal order, and set information, in Experiments 2 and 3. On first look, the data from Experiments 1, 3, and 4 seemed to contradict the account by showing difficulties in item memory. Closer inspection of the data, however, supported the idea of particular relational binding difficulties in ASD. In

Experiment 1, a deficit in overall recognition memory for single items was restricted to episodic Remembering, whereas semantic Knowing was intact. Since R responses required the retrieval of item, as well as context information, reduced R responses also indicated difficulties to process relational information. Similarly, in Experiment 3, because of the relational nature of the task, presenting three items together with several context details, performance potentially benefitted from relational processing. Reduced item memory in Experiment 4 may have been caused by the fact that participants had not been asked to study item information intentionally. Therefore, the current thesis identified conditions under which item memory was impaired in ASD:

1) When tasks were used that were matched in complexity to relational memory tasks. Complexity was, thereby, defined by the number of concrete units and their relations that needed to be processed at the same time.

2) When the tasks probed relational processing.

3) When information was tested that had not been studied intentionally.

4) When tasks were used that provided less support at test.

5) When tasks included the presentation of more than one type of context information that needed to be processed for successful performance.

Each of these factors should be manipulated, specifically, in suitable paradigms to resolve the open question of item memory difficulties in ASD. Overall, the findings presented in the thesis provided some support for theories suggesting an involvement of the hippocampus in the memory abnormalities reported in ASD. However, the findings also suggested that the hippocampus is not the only neural substrate for memory abnormalities in ASD, and that additional brain bases needed to be examined.

6.2.2.2   Complexity account and executive functions

Support for this account (see Sections 1.2.2, 1.2.3, 1.4.2.2) was found in Experiments 3 and 4. In Experiment 3, it was established that ASD individuals showed difficulties in item memory tests, when procedures were used that were similarly complex for item and relational memory. In addition, the findings from Experiment 4 suggested that different forms of spatial navigation were affected in ASD, when procedures were matched on complexity. As suggested in Section 1.4.2.2, one way around the circularity of this account was to define complexity in terms of the number of concrete units and the number of their relations that needed to be processed or bound at the same time.

Regarding EFs, the aim of the account, namely to find a difficulty that is common to all ASD individuals (Ozonoff et al., 1991), was not supported by the results found in the studies of this thesis. Whereas difficulties in EFs were related to impaired spatial navigation performance in ASD in Experiment 4, and which may have been responsible for the surprisingly lower performance of the older ASD individuals in the sample on egocentric navigation, tests of EFs used in Experiment 5 did not reveal any difficulties in another ASD sample.

Overall, the findings of this thesis suggested that complexity, as well as EFs are important factors to consider in research on memory in ASD. Maister et al. (2013) used an interesting approach to do this by dividing up their groups by performance on EF tasks. The authors showed that difficulties in memory in ASD only persisted in individuals that also had significant difficulties with EFs. It is, however, unclear if Maister et al.'s ASD and TD groups were still matched on IQ and age, after dividing the groups by their EF performance, or if ASD individuals with lower EFs also had significantly lower IQs. Therefore, the suggestion for future research would be to consider EFs as another matching variable in studies on memory in ASD by testing larger samples with ASD and TD subgroups that should be matched on their levels of EFs, as well as IQ, age, and gender.

6.2.2.3 Ageing analogy

The ageing analogy (see Section 1.4.2.3) was supported, partly, by the findings reported in this thesis. Support was found, when looking at a direct comparison of relational order memory in ASD and TD adults in Experiment 3. Younger as well as older ASD individuals performed like older TD participants, supporting the suggestion that the ASD memory profile would be similar to that found in TD OA. In Experiment 3, individuals until the age of 65 years were considered. The question arises what happens to ASD memory beyond the age of 65 years. There are three possibilities here (also see Geurts & Vissers, 2012). ASD and TD memory may be affected by age similarly, or ASD memory may be less or more affected by age than memory in TD OA. The current thesis found support for two of these possibilities. Whereas Experiments 1, 3, and 4 reported smaller age-related differences in memory and spatial navigation in ASD as opposed to TD participants, Experiment 2 found a larger age-related difference in explicit relational memory for ASD compared to TD adults. The question arises, why the four studies found different results. It is possible that age-related memory effects in TD individuals in Experiment 2 were obscured by a ceiling effect. It is, however, also possible that slightly different groups of ASD individuals were tested in the four studies, or that difficulties were probed differently by the various tasks. Whereas in Experiment 2, the younger individuals in both groups performed similarly, in Experiments 1, 3, and 4, younger ASD individuals showed much lower performance compared to younger TD adults, suggesting that memory and spatial navigation tested in these studies may have been particularly difficult for ASD individuals, for example, because of their stronger reliance on relational processing (Experiments 1 and 3) or EFs (Experiment 4). This idea was supported by the somewhat surprising finding of larger age-related differences in egocentric navigation in ASD in Experiment 4 of this thesis, which was not predicted by the findings on TD OA. It is possible that ASD individuals may have used processes depending on frontal lobe functions as compensatory mechanisms for memory processes affected by hippocampal

dysfunction, and when tasks specifically probed frontal lobe functions, these compensatory mechanisms no longer worked, thus revealing difficulties in areas that would not be predicted to be difficult by the ageing analogy. In general, when considering that ASD spans a spectrum of individuals with varying levels of abilities, it is possible that all three possibilities (weaker, stronger, or similar effects of age in ASD compared to TD OA) may happen in different subgroups of older ASD individuals. ASD persons tested in this thesis were a self-selected population with average intellectual abilities and an interest in research, but also less verbal and intellectually able ASD individuals grow older. Howlin et al. (2014) found that, whereas cognitive functions remained stable in most older ASD individuals, a steep decline in cognitive functions, that in some cases prevented further inclusion in research studies, occurred in 25 % of older ASD individuals. It would be very important, to find out more about these individuals using measures suitable to assess individuals with various intellectual functions, such as pupil size (see Experiment 1) and eye-movement measurements (Experiment 2), or tasks including minimal verbal instructions, such as adaptations from the animal learning and memory literature (Experiment 5).

Similarities between ASD and TD OA's memory were also found in the pupil size measurements of Experiment 1. The lack of the pupil Old/New effect in ASD individuals may have indicated cognitive overload and task disengagement leading to a "levelling", i.e., a decrease in pupil size for old items. Similarly, in a working memory task, pupil size has been found not to distinguish between lower and higher cognitive loads in TD OA (Van Gerven et al. 2004), possibly indicating cognitive overload. Experiment 2 found support for the ageing analogy, partly, when using a direct adaptation of a paradigm previously tested in TD OA (Kessels et al., 2005b). Similarly to TD OA, ASD individuals showed difficulties with explicit relational memory but intact implicit relational memory. These findings were, however, qualitatively different in ASD and TD OA. Whereas ASD individuals struggled to

place an object into its previously studied location, but performed well in placing an object into a new location, TD OA struggled with both tasks. They replaced fewer old objects into their previously studied locations, when instructed to do so, and they placed more old objects into their old locations, when instructed to find a new location (Kessels et al., 2005b). It is possible that in Experiment 2 of this thesis, a difference between ASD and TD adults in the exclude condition may have been masked by a ceiling effect. This explanation is, however, unlikely when looking at the small effect size for the between-group difference. Experiment 4 also adapted a paradigm from the TD ageing literature. Unlike TD OA, who showed a specific spatial navigation deficit in performance on different direction (allocentric) trials (Wiener et al., 2012; 2013), a preference for extra-hippocampal strategies (Wiener et al., 2013), and specific difficulties with a switch to an allocentric navigation condition (Harris et al., 2012), ASD individuals showed an overall navigation deficit in Experiment 4 characterised by difficulties in same (egocentric) and different direction (allocentric) trials, and by difficulties in flexibly switching between allocentric and egocentric navigation conditions. It is possible that the differences between studies may have been related to methodological issues. Wiener et al. (2013) excluded a considerable number of TD OA ($N =$ 6; 26 %) from their sample, because they did not perform well enough in the egocentric condition. The exclusion of these participants may have masked co-existing egocentric navigation difficulties in TD OA in this study. It is, however, also possible that the general navigation deficit in ASD, found in Experiment 4, may have been related to EF impairments that may be more severe in ASD compared to TD OA, and the tasks' demands on frontal lobe functions. Only a direct longitudinal comparison between younger and older ASD and TD individuals will confirm or disprove these ideas.

Overall, the findings presented here suggested that, in addition, to the hippocampus and the PFC, which are affected by typical ageing (Hedden & Gabrieli, 2004), other brain bases for memory difficulties in ASD should be considered.

6.2.2.4 Parietal account alone or in conjunction with other brain regions

Other candidate brain regions to consider as the basis for memory difficulties in ASD, supported by the studies of this thesis, were the parietal lobes (see Sections 1.2.7, 1.4.2.4, 1.4.2.5.2). Similarly to patients with parietal lobe lesions (Cabeza et al., 2008), ASD individuals tested in this thesis showed specific difficulties with EM in Experiments 1, 2, and 3. For example, Experiment 1 showed reduced R responses for ASD individuals, and the parietal lobes have previously been reported to be involved in R responses (Wagner et al., 2005).

Because the parietal lobes have also been found to be involved in the process of attention (e.g., Townsend et al., 1996; Section 1.2.7), atypical attention in ASD may have pointed to their role in the cognitive processes in ASD. The studies of this thesis suggested that atypical attention may have contributed to the memory difficulties observed in ASD. This was especially the case for Experiment 2, where less attention to context information at encoding was related to implicit object-location memory at test. Similarly, less attention to cues, while encoding the route through the maze, may have contributed to the memory and navigation deficits in ASD observed in Experiment 4. Attention differences were also found in the retrieval eye-movement data in Experiment 4, indicating that ASD individuals may have not been able to distinguish well between previously studied presentations of an intersection and new unseen presentations coming from a different direction.

Overall, the theories presented here have been fruitful for the characterisation of the memory profile in ASD, but none explains all the difficulties completely. All of them seem too simplifying and a combination of the different theories may be best by examining EFs and complexity, memory and attention, and how these processes influence one another. In addition, there are other factors that may play a role in the memory difficulties in ASD such as ToM and perception, which will be considered next.

6.2.3 Conclusions for cognitive theories in ASD

6.2.3.1 ToM deficit account

ToM was not directly tested in the studies of this thesis. However, since ToM has been suggested to be related to EM (Perner et al., 2007), EM impairments in ASD reported in Experiments 1, 2, and 3 suggested that the tested ASD samples may have also been affected by difficulties in ToM, or by differences in the process/processes that are common to ToM and EM. In particular, the difficulties in distinguishing between old and new items in ASD found in Experiments 1, 3, and 4 indicated a lack of a representation of the previous study episode and, therefore, a ToM impairment.

6.2.3.2 Weak Central Coherence and Atypical Perceptual Processing

Perception was also not directly tested in this thesis. Behavioural, as well as eye-movement data, however, suggested that atypical perception may have contributed to the reported findings on memory. The data from Experiment 5 indicated a local bias in ASD in the processing of the compound stimuli that were used as material. In particular, ASD individuals seemed to have processed both sides of the images separately and, therefore, did not take into account the structure of the whole image, leading to a deficit in structural learning and reduced transfer to unstudied probe trials at the final test stage. Eye-movement data from Experiments 2 and 4, however, did not suggest a local bias, as they showed reduced attention

to details such as location information and navigation cues in ASD compared to TD individuals. There has been growing awareness that low-level perceptual processes have a significant impact on memory in terms of encoding and later memory retrieval in disorders such as schizophrenia (e.g., Haenschel et al., 2007). Given possible parallels between ASD and schizophrenia (e.g., Brüne, 2005; Granholm et al., 1997; Orellana & Slachevsky, 2013; Williams et al., 2010), the influence of perceptual processes on memory is an important area for future research in ASD in terms of cross-disorder research to find out what is really unique to ASD.

6.2.3.3   Increased Perceptual Discrimination account

Support for this account was found in two studies of this thesis. The R justifications, given by participants in Experiment 1, showed that ASD individuals connected the studied materials less with information that was not part of the immediate study context, such as previously experienced events, therefore, indicating reduced transfer of information across different (study) episodes. Reduced transfer of information from the study to the test phase was found in Experiment 5, in that ASD individuals performed better on the re-paired probe trials, compared to previously studied trials, in Block 5 of Structural Discrimination, suggesting that they did not take into account the structure of the stimuli, therefore, being less hindered by it, when presented with the mirror images at test.

In conclusion, there is not one single cognitive theory that satisfactorily explains all the findings of the present thesis on memory in ASD. Some support but also contradictory findings were reported for all theories.

6.2.4 Conclusions for ASD

Two findings of this thesis advanced our knowledge of ASD more broadly. The first was that a fundamental learning mechanism, i.e., structural learning (tested in Experiment 5), was found to be disturbed in ASD, and abnormalities in structural learning may potentially be able to explain difficulties seen in ASD more generally, such as in the areas of learning, memory, spatial navigation, and social cognition. Future research should consider the examination of the relation between structural learning and the core symptoms in a more representative sample of ASD individuals that spans more or less the entire spectrum, which would be possible with the paradigm used in Experiment 5, since it involved minimal verbal instructions.

The second important finding was the absence of the pupil Old/New effect found in Experiment 1 and, therefore, the possibility of a biomarker for ASD, which could, potentially, be used in the diagnostic process. More research is needed to clarify the specificity of this effect for ASD. The lack of an overlap of findings between ASD and amnesia seemed encouraging. The potential of a biomarker as well as other future research directions will now be discussed.

6.3 Future research

At least six future research directions that directly follow from the results reported in this thesis are imaginable and some information related to each of them will now be provided.

One question that arose in several experiments was, whether relational processing is impaired in ASD, or whether ASD individuals just show an item processing preference and would, in principle, be able to use relational processing, for example, when they are provided with task support, such as specific task instructions. Possible experiments to tackle this question would be: First, a replication of Experiment 3 with item and relational processing instructions to see if TD individuals' performance decreased in the item and relational tasks,

following an item specific instruction, and if ASD individuals' performance increased in item and relational tasks, following relational processing instructions. Second, in a replication of Experiment 4, it should be tested whether ASD individuals' navigation performance would increase, when they were specifically instructed to attend to the landmark cues and relate them to one another and the travel direction through the maze. Third, a replication of Experiment 5 would be possible with an instruction to attend to the global structure of the compound stimuli to test whether ASD individuals would, in principle, be able to acquire structural learning, and to examine whether their learning and test performance would improve.

A second question is related to the suggestions made in Section 6.2.2.1 about the conditions under which item memory would be intact or impaired in ASD. These suggestions should be tackled in separate experiments with large enough samples to provide sufficient statistical power, each manipulating one factor, such as task complexity, study intention, task support at study and/or test, and number/ types of context information included in the task.

A third important area to follow up on is how ageing affects individuals with ASD and their cognitive profiles beyond the age of 65 years, and whether individuals with higher and lower verbal and/or intellectual abilities are affected differently by the ageing process. For this, suitable measures would need to be found. One possibility would be to use eye-movement and pupil size measurements to test a wide range of individuals with differing abilities with the same or similar tasks.

A fourth strand of research is related to the idea of subgroups with different cognitive profiles in ASD and the suggestion made in Section 6.2.2.2 to test the influence of other cognitive functions such as EFs on the memory profile reported in ASD, by testing large enough subgroups of ASD and TD individuals that are matched on their EF abilities.

The further development and application of memory paradigms suitable for young and less verbal and/or intellectually able ASD individuals would form a fifth area of research. Experiment 5 was a direct adaptation of an animal learning paradigm presented to participants with little in the way of verbal instructions and by using a touch-screen laptop. It was a collaborative investigation with Claire Thomas Derwent, who is currently testing minimally verbal children with ASD using the same paradigm as the one presented in this thesis. In a similar vein, eye-tracking and pupillometry also seemed promising technologies with the measures used in Experiments 1, 2, and 4, constituting measures of real memory phenomena that showed sensitive results, which, at least in part, were not established by means of more conventional behavioural measurements. The paradigms used in this thesis would need to be simplified in order to make them suitable for individuals with lower verbal and/or intellectual abilities. One possibility would be, to reduce the R/K procedure used in Experiment 1 to an Old/New recognition procedure, by presenting participants with a number of items to study, and by measuring their pupil responses to the studied and new items at test.

A final, potentially important, area of follow-up research is the finding of a lack of the pupil Old/New effect and its potential use as a biomarker. Three areas of research would be important: First, the different interpretational possibilities suggested in Section 2.1.4 should be tested with suitable behavioural paradigms to obtain clarity on whether the absence of such an effect in ASD indicated cognitive overload and task disengagement, a lack of interest, reduced memory strength, or whether it is related to lower emotional responsiveness. Second, groups of individuals with different disorders should be compared to ASD individuals to investigate the uniqueness and specificity of this effect in ASD. Third, more information should be gathered about the underlying mechanisms of the pupil Old/New effect by combining methods, such as tests of behaviour, physiology, and neurochemistry.

6.4 Concluding remarks

The overall aim of this thesis was to refine the cognitive profile observed in ASD by testing distinctions from the memory literature, and by investigating memory-related cognitive processes, such as attention, EFs, spatial navigation, and learning, to avoid seeing memory as detached from the context, in which it appears. In addition, it was aimed to find and test suitable physiological measures for memory in ASD, and to draw conclusions as well as generate hypotheses in relation to cognitive theories and underlying brain bases and mechanisms.

The biggest achievements of the research presented in this thesis were:

1) Advances in the fields of item and relational memory in ASD were made in the discovery of conditions under which item memory was impaired in ASD (i.e., particularly, when performance benefitted from relational processing), and in the finding that different types of relational memory were similarly affected in ASD, supporting the idea of reduced relational processing in ASD.

2) The areas of explicit and implicit memory in ASD were significantly advanced by the finding that the relational memory impairment in ASD went beyond explicit memory, in that implicit relational memory was also affected, and by the connections that were drawn between the memory distinctions of implicit and explicit, direct and indirect, and item and relational memory.

3) Another significant contribution was the finding that the memory processes encoding, consolidation, and retrieval should not be considered in isolation. Experiments 2 and 4 have shown encoding differences that, potentially, affected later memory retrieval in ASD.

4) The discovery of suitable eye-movement and pupil size measures to test memory in ASD was important in that behavioural findings were replicated with a second measure, questions were answered that would have remained unanswered by the sole use of behavioural measures, and because it led to the suggestion of a pupil size biomarker in ASD.

5) A final important advancement related to the finding that cognitive processes should not be considered in isolation from one other, but that the ways in which they influence each other should be tested. In examining the roles of EFs, attention, memory, and related processes, such as learning and spatial navigation, it should be remembered that an abnormality in one, single process is unlikely to explain all difficulties observed in ASD.

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Appendices

Appendix 1: Table of materials used in Experiment 1, criteria for materials, instructions for Type A and Type B for the R/K test

Table A1.1

Complete overview of the materials used. Lists were counterbalanced across participants.

Material type	List 1	List 2	List 3	List 4
Words	apple	candle	anchor	lemon
	ashtray	doll	cake	bicycle
	balloon	flag	crown	cannon
	button	grapes	eagle	clock
	drum	lamp	ladder	elephant
	fork	peanut	onion	guitar
	hammer	rabbit	shoe	sandwich
	monkey	scissors	toaster	skirt
	shirt	sock	trumpet	stool
	tomato	violin	umbrella	whistle
Pictures				
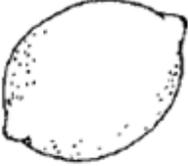
Material type	List 1	List 2	List 3	List 4
Pictures	ashtray	doll	cake	bicycle
	balloon	flag	crown	cannon
	button	grapes	eagle	clock
	drum	lamp	ladder	elephant
	fork	peanut	onion	guitar
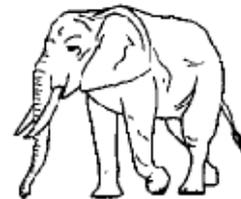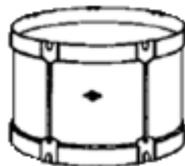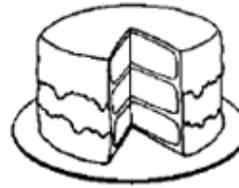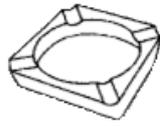
Material type	List 1	List 2	List 3	List 4
Pictures				
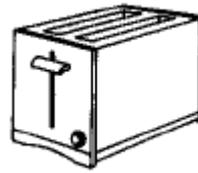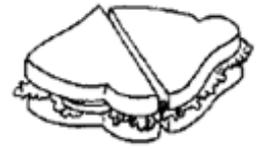
Shapes

Material type	List 1	List 2	List 3	List 4

Material type	List 1	List 2	List 3	List 4
Shapes				
Non-words	pennel	rubid		
	ballop	diller		
	honder	natem		
	frescovent	hampent		
	trumpetine	glistow		
	doppelate	barrazon		
	bannifer	commerine		
	sladding	thickery		
	tafflest	brasterer		
	prindle	skiticult		

Table A1.2

Criteria for lists of pictures and words according to Snodgrass and Vanderwart (1980).

Criterion	List 1 M (*SD*)	List 2 M (*SD*)	List 3 M (*SD*)	List 4 M (*SD*)	$F(3,40)$	p	η_p^2
Letter nr[a]	5.70 (1.16)	5.50 (1.43)	5.70 (1.34)	6.20 (1.23)	0.53	.66	.04
Name agre[b]	0.98 (0.04)	0.93 (0.09)	0.92 (0.09)	0.97 (0.04)	1.80	.17	.13
Image agre[c]	3.91 (0.45)	3.77 (0.68)	3.55 (0.50)	3.70 (0.68)	0.63	.60	.05
Familiarity	3.58 (0.79)	3.39 (0.65)	3.15 (1.07)	3.25 (0.93)	0.45	.72	.04
Complexity	2.47 (0.70)	2.73 (0.90)	3.18 (0.65)	3.01 (0.98)	1.46	.24	.11
Frequency[d]	10.30 (7.02)	10.20 (5.85)	11.50 (6.26)	11.90 (6.77)	0.17	.91	.01

Note. [a]Letter number. [b]Name agreement. [c]Image agreement. [d]Word frequency - Kucera & Francis.

A1.3: Instructions for Type A and Type B for the R/K test

In this test you will see a series of items on the screen one at a time. Some of these items are ones that you saw earlier in this experiment when you were asked to try and memorize the items that appeared on the screen, and some of the items are not items that you have seen in this experiment.

If you are sure that you recognize the item as being one that you saw earlier in this experiment, then please click on the "YES" box on the screen. If you DO NOT recognize the item as being one that you saw earlier in this experiment, then please click on "NO". If you are not sure if the item was one that you saw earlier or not, then please click on "NO." Only say YES if you are SURE that the item is one that you saw on the screen earlier.

After you say YES, you will be asked to make another choice about HOW you remember the item. The choice is between TYPE A and TYPE B. TYPE A and TYPE B are two different ways that people remember things.

A TYPE A memory is when you remember seeing the item in this experiment, and you also remember something about when you actually saw the item. You might remember where the item was in the list of items, what it looked like on the screen, something about what you thought about at the time when you saw the item, or you might remember a picture that you had in your head when you saw the item. A TYPE A kind of remembering is when you remember that the item was on the list of items to remember, and you also remember something about the time when you actually saw the item.

TYPE B is the other way that people can remember things. A TYPE B kind of memory is when you are sure that the item was on the list of items to be remembered but you can't remember any details about the time that you saw it. For example a TYPE B memory is when you can't remember where the item was in the list, or anything that you thought about at the time, or any picture that you might have had in your head at the time. A TYPE B kind of remembering is when you know that the item was on the list of items that you were asked to remember but you can't remember anything about the actual time when you saw the item on the screen. You have this feeling of familiarity. An example from daily life would be that sometimes you meet a person in the street and you are sure you have seen this person before but you can't remember anything else about them, e.g., their name or where you know the person from.

Please ask for help if you have any problems, or you don't understand what you are to do during the test.

Appendix 2: Table of materials used in Experiment 2

Table A2

List of rooms and objects for practice, and test and which sets they were studied in. Set A was used as study set for one half of the participants. They received Set B as new items at test. The other half of the participants studied Set B and received Set A as the new items at test.

Room	Object	Set
practice		
Garden	Mower	studied in Set A
Garden	Milk can	studied in Set A
Garden	Birdhouse	studied in Set A
Garden	Watering can	studied in Set B
Garden	Spade	studied in Set B
test		
Bathroom	Bath brush	studied in Set A
Bathroom	Bathing slippers	studied in Set A
Bathroom	Scales	studied in Set A
Bathroom	Shaver	studied in Set A
Bathroom	Soap	studied in Set B
Bathroom	Toilet paper	studied in Set B
Bathroom	Toothbrush	studied in Set B
Bathroom	Shampoo	studied in Set B

Room	Object	Set
Living room	Videocassette	studied in Set A
Living room	Candle	studied in Set A
Living room	CD collection	studied in Set A
Living room	clock	studied in Set A
Living room	Radio	studied in Set B
Living room	Remote	studied in Set B
Living room	Wine bottle	studied in Set B
Living room	Books	studied in Set B
Kitchen	Washing-up liquid	studied in Set A
Kitchen	Cheese	studied in Set A
Kitchen	Potatoes	studied in Set A
Kitchen	Eggs	studied in Set A
Kitchen	Knife block	studied in Set B
Kitchen	Cloths	studied in Set B
Kitchen	Spatula	studied in Set B
Kitchen	Saltshaker	studied in Set B
Bedroom	Book	studied in Set A
Bedroom	House shoes	studied in Set A
Bedroom	Night cream	studied in Set A
Bedroom	Pillow	studied in Set A
Bedroom	Socks	studied in Set B
Bedroom	Tie	studied in Set B

Room	Object	Set
Bedroom	Underpants	studied in Set B
Bedroom	Teddy	studied in Set B
Office	Agenda	studied in Set A
Office	Stapler	studied in Set A
Office	Letter tray	studied in Set A
Office	Desk tidy	studied in Set A
Office	Briefcase	studied in Set B
Office	Hole puncher	studied in Set B
Office	File	studied in Set B
Office	Biro	studied in Set B
Storeroom	Bag	studied Set A
Storeroom	Carton	studied Set A
Storeroom	Cooler	studied Set A
Storeroom	Dartboard	studied Set A
Storeroom	Cable spool	studied in Set B
Storeroom	Keys	studied in Set B
Storeroom	Painting	studied in Set B
Storeroom	Polish	studied in Set B

Appendix 3: Tables of materials and reinforcement contingencies used in Experiment 5

Table A3.1

Stimulus examples for Structural Discrimination with reinforced and incorrect shapes, number of presentations for each pair within one block and criterion to continue to the next block. If the criterion was not reached within three attempts of a certain block, the programme continued automatically to the next block.

Block	Correct stimulus	Incorrect stimulus	Number of presentations	Criterion
1			5 right 5 left	80 % correct
1			1 right 1 left	50 % correct
2			1 right 1 left	50 % correct
2			1 right 1 left	50 % correct
2 new			5 right 5 left	80 % correct
3			1 right 1 left	50 % correct
3			1 right 1 left	50 % correct

Block	Correct stimulus	Incorrect stimulus	Number of presentation	Criterion
3			1 right 1 left	50 % correct
3 new			5 right 5 left	80 % correct
4			2 right 2 left	75 % correct
4			1 right 1 left	50 % correct
4			2 right 2 left	75 % correct
4			2 right 2 left	75 % correct
5			2 right 2 left	-
5			2 right 2 left	-
5			2 right 2 left	-
5			2 right 2 left	-
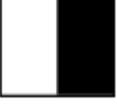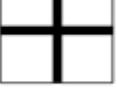
Block	Correct stimulus	Incorrect stimulus	Number of presentations	Criterion
5 **probe**			2 right 2 left	-
5 **probe**			2 right 2 left	-
5 **probe**			2 right 2 left	-
5 **probe**			2 right 2 left	-
5 **probe**			2 right 2 left	-
5 **probe**			2 right 2 left	-

Table A3.2

Stimulus examples for Biconditional Discrimination with reinforced and incorrect shapes, number of presentations for each pair within one block and criterion to continue to the next block. If the criterion was not reached within three attempts of a certain block, the programme continued automatically to the next block.

Block	Correct stimulus	Incorrect stimulus	Number of presentations	Criterion
1			5 right 5 left	80 % correct
1			1 right 1 left	50 % correct
2			1 right 1 left	50 % correct
2			1 right 1 left	50 % correct
2 new			5 right 5 left	80 % correct
3			1 right 1 left	50 % correct
3			1 right 1 left	50 % correct
3			1 right 1 left	50 % correct

Block	Correct stimulus	Incorrect stimulus	Number of presentations	Criterion
3 new			5 right 5 left	80 % correct
3 new			5 right 5 left	80 % correct
4			2 right 2 left	75 % correct
4			1 right 1 left	50 % correct
4			2 right 2 left	75 % correct
4			2 right 2 left	75 % correct
4			2 right 2 left	75 % correct
5			2 right 2 left	-
5			2 right 2 left	-
5			2 right 2 left	-
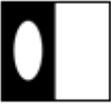
Block	Correct stimulus	Incorrect stimulus	Number of presentations	Criterion
5			2 right 2 left	-
5			2 right 2 left	-
5 probe			2 right 2 left	-
5 probe			2 right 2 left	-
5 probe			2 right 2 left	-
5 probe			2 right 2 left	-

Table A3.3

Stimulus examples for Transverse Patterning with reinforced and incorrect shapes, number of presentations for each pair within one block and criterion to continue to the next block. If the criterion was not reached within three attempts of a certain block, the programme continued automatically to the next block.

Block	Correct stimulus	Incorrect stimulus	Number of presentations	Criterion
1			5 right 5 left	80 % correct
1			1 right 1 left	50 % correct
2			1 right 1 left	50 % correct
2			1 right 1 left	50 % correct
2 new			5 right 5 left	80 % correct
3			1 right 1 left	50 % correct
3			1 right 1 left	50 % correct
3			1 right 1 left	50 % correct

Block	Correct stimulus	Incorrect stimulus	Number of presentation	Criterion
3 new	[horizontal stripes]	[black]	5 right / 5 left	80 % correct
4	[black]	[white]	2 right / 2 left	75 % correct
4	[cross]	[filled circle]	1 right / 1 left	50 % correct
4	[white]	[horizontal stripes]	2 right / 2 left	75 % correct
4	[horizontal stripes]	[black]	2 right / 2 left	75 % correct
5	[black]	[white]	4 right / 4 left	-
5	[cross]	[filled circle]	2 right / 2 left	-
5	[white]	[horizontal stripes]	4 right / 4 left	-
5	[horizontal stripes]	[black]	4 right / 4 left	-

Object-Location Memory in Adults with Autism Spectrum Disorder

Melanie Ring, Sebastian B. Gaigg, and Dermot M. Bowler

This study tested implicit and explicit spatial relational memory in Autism Spectrum Disorder (ASD). Participants were asked to study pictures of rooms and pictures of daily objects for which locations were highlighted in the rooms. Participants were later tested for their memory of the object locations either by being asked to place objects back into their original locations or into new locations. Proportions of times when participants choose the previously studied locations for the objects irrespective of the instruction were used to derive indices of explicit and implicit memory [process-dissociation procedure, Jacoby, 1991, 1998]. In addition, participants performed object and location recognition and source memory tasks where they were asked about which locations belonged to the objects and which objects to the locations. The data revealed difficulty for ASD individuals in actively retrieving object locations (explicit memory) but not in subconsciously remembering them (implicit memory). These difficulties cannot be explained by difficulties in memory for objects or locations per se (i.e., the difficulty pertains to object-location relations). Together these observations lend further support to the idea that ASD is characterised by relatively circumscribed difficulties in relational rather than item-specific memory processes and show that these difficulties extend to the domain of spatial information. They also lend further support to the idea that memory difficulties in ASD can be reduced when support is provided at test. *Autism Res* 2015, 8: 609–619. © 2015 International Society for Autism Research, Wiley Periodicals, Inc.

Introduction

Autism Spectrum Disorder (ASD) is associated with a heterogeneous cognitive profile with a consistent pattern of strengths and weaknesses in the domain of memory (see Boucher & Bowler, 2008; Boucher, Mayes, & Bigham, 2012 for reviews). ASD individuals experience difficulties with free recall where information needs to be remembered without retrieval support. This is especially marked when categorical information is available in the studied material that typically facilitates memory [Bowler, Matthews, & Gardiner, 1997; Gaigg, Gardiner, & Bowler, 2008; Tager-Flusberg, 1991]. By contrast, when test procedures provide support for retrieving studied information, memory tends to be spared in ASD. Supported procedures include immediate cued recall [e.g., Mottron, Morasse, & Belleville, 2001] and recognition memory tasks [e.g., Boucher et al., 2005; Bowler, Gardiner, & Grice, 2000a; Bowler, Gardiner, Grice, & Saavalainen, 2000b; Kuusikko-Gauffin et al., 2011]. The pattern of performance on supported and unsupported memory tests led Bowler et al. [1997] to propose the "task support hypothesis"

suggesting that ASD participants perform as well as typically developing (TD) individuals when procedures are used that scaffold retrieval. Since then various studies have confirmed this idea [Bowler, Gardiner, & Berthollier, 2004; Gaigg et al., 2008; Ring, Gaigg, Altgassen, Barr, & Bowler, under review).

Further characteristics of memory function in ASD are relatively pervasive difficulties in remembering the temporal order of events [Poirier, Martin, Gaigg, & Bowler, 2011; Gaigg, Bowler, & Gardiner, 2014] and in remembering the autobiographical past and imagining the autobiographical future [e.g., Crane, Goddard, & Pring, 2009; Lind & Bowler, 2010]. These suggest difficulties particularly with episodic memory, which requires the binding of the spatial-temporal context that defines specific events. Interestingly, when participants with ASD are tested on where, when or how they studied certain stimuli (source memory tasks), findings are inconsistent. Some studies suggest impaired source memory in ASD [e.g., Bowler et al., 2004; Lind & Bowler, 2009], whereas others do not [e.g., Bowler et al., 2004; Souchay, Wojcik, Williams, Crathern, & Clarke, 2013]. Importantly, here as well, difficulties

Relational Memory Processes in Adults with Autism Spectrum Disorder

Melanie Ring, Sebastian B. Gaigg, and Dermot M. Bowler

Research into memory in Autism Spectrum Disorder (ASD) suggests intact item memory but difficulties in forming relations between items (Bowler, Gaigg, & Lind, 2011). In this study, we tested memory for items as well as for sequential, spatial, and associative relations between items with the same paradigm using abstract shapes in ASD and typically developing (TD) individuals. Participants studied shape triplets on a computer screen and memory was subsequently tested either for the individual items making up the triplets, the screen-locations, the order or the combinations of items presented at study. Contrary to our predictions, performance was significantly lower in the ASD group on all four tasks. The result raises questions about how intact item memory is in ASD, which role task complexity plays, and how item-specific versus relational processing affect task performance. One possibility is that TD individuals relied more on relational processing in the current study and might have therefore had an advantage over ASD individuals. This idea is supported by the result of a preliminary analysis of age-related differences in memory across the midadult lifespan in both groups. Age seems to affect order memory less in ASD compared with TD individuals where it leads to a significant decrease in performance. This might indicate a decrease in relational processing in TD but not ASD individuals with increasing age. More research is needed to answer questions about the change in cognition in ASD individuals across the lifespan. *Autism Res* 2016, 9: 97–106. © 2015 International Society for Autism Research, Wiley Periodicals, Inc.

Keywords: item memory; relational memory; autism spectrum disorder; ageing

Introduction

Autism Spectrum Disorder (ASD) is characterized by difficulties in social interaction, social communication, and by the presence of restricted and repetitive behaviours [American Psychiatric Association, 2013]. In addition, it is associated with a complex cognitive profile which includes a particular pattern of strengths and weaknesses in the domain of memory [Boucher & Bowler, 2008; Boucher, Mayes, & Bigham, 2012]. Previous research suggests intact performance on tasks that probe memory for individual items of information such as individual words or pictures of objects that make up a study list [Bowler, Gardiner, & Grice, 2000; Hauck, Fein, Maltby, Waterhouse, & Feinstein, 1998]. In addition, performance is typically also preserved on supported test procedures such as recognition tests where participants only need to identify rather than generate the studied items [task support hypothesis—Bowler, Gardiner, & Berthollier, 2004]. By contrast, difficulties are often observed on tasks that probe memory for associations between items [Bowler, Gaigg, & Gardiner,

2008; Gaigg, Gardiner, & Bowler, 2008] or between items and their context. Examples of the latter are difficulties in remembering the locations for or colors of objects [Bowler, Gaigg, & Gardiner, 2014; Ring, Gaigg, & Bowler, 2015; Semino, Gaigg, Bowler, & Ring, 2013], remembering the temporal order of items [Gaigg, Bowler, & Gardiner, 2014; Poirier, Martin, Gaigg, & Bowler, 2011], or recalling in what modality words were presented or by whom [Bowler et al., 2004]. Memory difficulties tend to be particularly pronounced in ASD when test procedures provide little support, such as in the case of free-recall test procedures [e.g., Bowler et al., 2008].

The aim of this study was to test the hypothesis that ASD is characterized by relatively specific difficulties in relational but not item memory. For the current study, we drew on a paradigm from the amnesia literature in which neurologically healthy participants and amnesic patients with either focal hippocampal or diffuse medial-temporal lobe (MTL) lesions were asked to study abstract shape triplets [Konkel, Warren, Duff, Tranel, & Cohen, 2008]. Different experimental conditions