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Event-Related Potential Brain Correlates of Episodic and Semantic Memory in Adults with Autism Spectrum Disorder

Esha Massand

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The number of TD participants to be included in each experiment was determined following previous research studies with similar numbers of ERP stimuli and trials. The researcher aimed to test an ASD group of comparable number to the TD group (individually matched on task-relevant characteristics); however this was not always attainable. ASD participants are not as available for testing as comparison

participants / cannot always complete long testing sessions. For the present research, where ASD group sizes are smaller than the TD group, the additional TD participants included in the study are matched to the group's average IQ and age characteristics. 68

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For Goldy

Declaration

I, Esha Massand, confirm that the work presented in this thesis is my own. Where information has been derived from other sources I confirm that it has been indicated.

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Abstract

The aim of this thesis was to refine current models of memory in Autism Spectrum Disorder (ASD) and elucidate similarities and differences between memory in ASD and that of Typically Developing (TD) individuals. This thesis built upon recently established behavioural patterns of preserved semantic and diminished episodic memory in ASD, by linking these with established patterns of electrophysiological activity in different cortical regions of the brain in TD individuals. Event-Related Potential (ERP) Old-New effects (enhanced positivity in the brain for correctly recognised Old stimuli compared to correctly rejected New stimuli) were recorded for episodic and semantic memory judgments (the parietal Old-New effect 400-800 ms, and the mid-frontal Old-New effect 300-500 ms respectively) in ASD, and were compared to TD individuals in terms of (1) temporal and (2) topographical similarities and differences. A series of five experimental studies were conducted using nameable line drawings, non-nameable kaleidoscope images and words as stimuli. A combination of two experimental paradigms were used; the Remember/Know paradigm and the Inclusion/Exclusion paradigm. The current thesis demonstrates that recognition memory Old-New effects are attenuated in ASD for word stimuli and nameable line drawings, but that the topography remains comparable between groups. The current findings suggest that although episodic memory is quantitatively diminished in ASD during behavioural tests, residual episodic memory judgements are phenomenologically similar to TD individuals. Despite demonstrating quantitatively preserved semantic memory, different patterns of neurophysiology are observed for these judgements in ASD, suggesting that different processes are engaged in this group. Finally, although individuals with ASD demonstrated diminished Old-New effects for nameable line drawing and word stimuli compared to TD individuals, enhanced Old-New effects were observed for non-nameable and novel kaleidoscope images in ASD. These findings have important implications for our understanding of verbal mediation and its relation to thought in ASD. The findings are interpreted within a theoretical account of diminished episodic memory and verbal processing difficulties in ASD.

List of Abbreviations

AS	Asperger Syndrome
ASD	Autism Spectrum Disorder
APA	American Psychiatric Association
AQ	Autism Quotient
DSM	Diagnostic and Statistical Manual of Mental Disorders
EEG	Electroencephalography
EF	Executive Functioning
ERP	Event-related Potential
FIQ	Full Intelligence Quotient
HFA	High Functioning Autism Spectrum Disorder
LFA	Low Functioning Autism Spectrum Disorder
M	Mean
PDD-NOS	Pervasive Developmental Disorder (Not Otherwise Specified)
PIQ	Performance Intelligence Quotient
SD	Standard Deviation
TD	Typically Developing
ToM	Theory of Mind
VIQ	Verbal Intelligence Quotient
WAIS	Wechsler Adult Intelligence Scale
WCC	Weak Central Coherence

Chapter 1 : LITERATURE REVIEW

1.1 Autism Spectrum Disorder

It is widely accepted that autism is a spectrum of conditions that varies in its severity. 'Autism Spectrum Disorder' or ASD (Wing, 1996), is the term commonly used to refer to the variants of this neuro-developmental disorder. The term encompasses individuals with Autistic Disorder or low functioning autism (LFA) who demonstrate learning disabilities (IQ under 70) as well as developmental language delay (as described by Kanner, 1943), and higher functioning people with autism (HFA) or Asperger Syndrome (AS) who exhibit only mild or no intellectual disability and no delay in language development. The category of Pervasive Developmental Disorder – Not Otherwise Specified (PDD-NOS) also constitutes part of the autism spectrum and together these variants are estimated to affect 116.1 per 10,000 individuals in the UK, with a male to female ratio of 3.3:1 (Baird, Simonoff, Pickles, Chandler, Loucas, Meldrum & Charman, 2006).

A diagnosis of Autistic Disorder, in accordance with the Diagnostic and Statistical Manual of Mental Disorders (DSM-IV, American Psychiatric Association, 2000), is given if there is a sustained and marked impairment in several areas of development including reciprocal social interaction skills, communication skills, or the presence of stereotyped behaviour, interests and activities. The impairments that define the disorder are characteristically and markedly deviant in relation to the individual's developmental level or mental age (American Psychiatric Association, 2000). Often, but not always, a diagnosis of Autistic Disorder can be qualified as LFA when it is accompanied by an intellectual disability, which can vary from mild to severe. LFA individuals are likely to appear aloof and ignore many of the social overtures of others, whilst HFA individuals are likely to be passive towards the social overtures of others, but take little initiative within social situations. Characteristically, an abnormal cognitive profile is observed where the individual's verbal intelligence quotient (VIQ) is lower than their performance intelligence quotient (PIQ). The most prominent distinction in ASD is between Autistic Disorder and AS. According to DSM-IV, AS is differentiated from Autistic Disorder by an absence of any clinically significant delay in early language development (single words are used by the child prior to 2 years of age and phrases used by 3 years). In addition, AS is characterised by an absence of clinically significant cognitive delay. The diagnosis of Pervasive Developmental Disorder Not Otherwise Specified (PDD-NOS) is given when there is a pervasive impairment in reciprocal social interaction with either impairment in (verbal or non-verbal) communication, or restricted, repetitive and stereotyped behaviours are present. This category is reserved for individuals who present sub-threshold or

atypical behavioural features (or perhaps late onset) meaning the criteria for Autistic Disorder or AS are not met.

According to the DSM-IV, the diagnoses of HFA and AS are differentiated by the presence of early language delay and cognitive delay in HFA individuals, but not AS individuals. This differentiation has led to some confusion and controversy with recent research showing no apparent or distinct profile to distinguish the two disorders (for reviews see Macintosh & Dissanayake, 2004; Sanders, 2009; Witwer & Lecavalier, 2008). As there is little evidence that they differ qualitatively in terms of features or cognitive profile, the disorder is widely considered a spectrum of conditions and instead the differences are thought to lie in the severity of behaviours and cognitive deficits (Macintosh & Dissanayake, 2004; Witwer & Lecavalier, 2008). Moreover, the prospects for DSM-V in terms of ASD diagnosis, are that Autistic Disorder and AS be combined into a spectrum of disorders (American Psychiatric Association, 2010 also see Volkmar, State & Klin, 2009 for a review of the diagnostic issues for autism and ASDs).

Despite the diverse presentation of the different parts of the autism spectrum, there are common threads that run throughout the whole spectrum. The core features of ASD, which Wing and Gould (1979) refer to as the 'triad of impairments', refer to the difficulties observed in one (and often more than one) area of the triad. This includes impairments in reciprocal social interaction, communication skills and their accompanying restricted, repetitive and stereotyped patterns of behaviour. These defining features are usually evident in the first years of life (prior to three years of age). As the aforementioned common threads of the condition are encapsulated by the term ASD (Wing, 1996), it will be used throughout the thesis to refer to individuals with a diagnosis of HFA, LFA or AS.

1.2 Psychological Explanations of ASD

1.2.1 Weak Central Coherence

People with ASD have been shown to have a distinctive style of cognitive processing that favours the local elements at the expense of the Gestalt whole (or higher level, contextual meaning). Frith (1991) has described this as a Weak Central Coherence (WCC). WCC has been demonstrated using the Block Design Test on the Wechsler intelligence scales for children and adults. In this task participants are asked to arrange a set of blocks (that all have red sides, white sides, and red plus white sides) into a pattern determined by the experimenter (Shah & Frith, 1993; Happé & Frith, 1994). Individuals with ASD are consistently observed to perform better than comparison individuals on this task, presumably because they are better able to segment the global pattern into its constituent local building blocks. WCC in ASD has also been

demonstrated with the Embedded Figures Test, which requires participants to search for a figure within a larger and more elaborate figure (Joliffe & Baron-Cohen, 1997; Shah & Frith, 1983, 1993). These tasks both require local and detailed processing, for which individuals with ASD show superior performance to comparison individuals. The first formulations of WCC (Happé & Frith, 1994) almost went as far to suggest that individuals with ASD *could not* see the 'global' meaning. However, a more recent review by Happé and Frith (2006) of over 50 empirical studies of coherence in ASD, has suggested mixed findings regarding global processing. This has led to a re-formulation of the early accounts of WCC. The focus shifted from the suggestion of a 'weak' central coherence and failure to extract global form and meaning in autism, towards the postulation that individuals with ASD can process information at the global level but show enhanced superiority for local processing and a detail-focused cognitive style. The tendency to process information at the local level in ASD has also been highlighted in several other related theoretical accounts, including the Enhanced Perceptual Functioning (EPF) theory, (Mottron, Dawson, Soulières, Hubert & Burack, 2006) and Enhanced Discrimination theory (Plaisted, 2001), and is now considered a processing style, rather than a particular processing deficit (Happé & Frith, 2006).

The theory of WCC, unlike other theories, also explains the enhanced performance of individuals with ASD on certain tasks. Furthermore, the theory is in line with the poor performance of ASD individuals on studies of visual illusions and context-dependent information (Happé, 1996; 1997) both of which require holistic processing. For example, in sentence completion tasks, individuals with ASD often produce inappropriate words because they seemingly fail to appreciate the globally constituted contextual meaning (e.g. "the sea is full of salt and…*pepper*"). WCC can play a role in everyday scenarios and can also be offered as an explanation for findings in memory, for example, when retelling a story, typical individuals (find it easier to) recall the whole gist of the story rather than the details (Bartlett, 1932), whereas individuals with ASD demonstrate the opposite profile, recalling the exact words rather than the gist (Frith & Hill, 2003). As with other accounts, some of the everyday behaviours of ASD individuals can be explained by the central coherence account. However, since WCC is not a universal phenomenon for all individuals with ASD (Norbury, 2005), further theories are necessary to explain the full range of autistic behaviour.

1.2.2 Impaired Executive Functioning (EF)

The non-social impairments of ASD, including restricted and repetitive stereotyped behaviours (rigidity and perseveration) are addressed by the EF theory of ASD. The term 'executive functions' (see Pennington & Ozonoff, 1996) comprises a set of higher order cognitive

functions such as planning, working memory, mental flexibility (shifting set), inhibition of pre-potent responses, generativity and action monitoring (Rabbitt, 1997). Several executive dysfunctions have been studied, however here the focus will be on planning, mental flexibility, and inhibition, as these areas of EF have been shown to pose most difficulty for individuals with ASD (see Pennington & Ozonoff, 1996; Hill, 2004b for reviews).

Poor performance on planning tasks, such as the Tower of Hanoi and the Tower of London, has been well documented in ASD (Sergeant, Guerts & Oosterlaan, 2002; Ozonoff & Jensen, 1999). These tasks typically involve moving disks from a prearranged sequence on pegs to a goal state in as few moves as possible, whilst observing a set of rules for changing the apparatus (e.g. do not put a bigger disk on a smaller one). The Tower of London task differs from the Tower of Hanoi task in that the goal state of the latter is fixed (a pyramid of disks) whilst it is determined by the experimenter in the Tower of London task. Children with ASD have been found to be impaired on such tasks (Ozonoff, Pennington & Rogers, 1991; Hughes, Russell & Robbins, 1994; Ozonoff & Jensen, 1999) and this impairment is maintained over time in longitudinal studies (Ozonoff & McEvoy, 1994). Taken together, this research suggests that planning impairments are common and pervasive for individuals on the autism spectrum, thus providing supporting evidence for the EF account of ASD.

A second component of EF – mental flexibility – is commonly measured using the Wisconsin Card Sorting Test (WCST) in which participants are required to match stimulus cards containing a certain number of coloured shapes, with target cards representing the same shapes, colours and numbers. Across trials, the rules for matching the cards are changed by the experimenter without alerting the participant, such that on some trials participants are praised for matching stimulus cards to target cards on the basis of 'shape' whilst on other trials they are praised for matching on the basis of 'colour' or 'number'. The WCST is thus thought to measure a participant's ability to learn a certain matching criterion and to avoid perseveration (i.e. persisting with the matching criterion when it is no longer valid). It also provides a measure for the various dimensions and categories of the stimulus-set that the participant is aware of (see Heaton, Chelune, Talley, Kay & Curtis, 1993). Individuals with ASD show a significant degree of impairment relative to comparison individuals when tested with the WCST, particularly with respect to perseveration (see Hill, 2004 a, b). These results suggest that mental flexibility is particularly impaired for this population.

In contrast to planning and mental flexibility, where evidence of difficulties is relatively consistent in ASD, findings concerning the EF domain of inhibition is somewhat mixed. Thus ASD individuals have demonstrated unimpaired performance in classic tests of inhibition such as the Stroop task, which involves naming the colour of ink in which words are written, rather than

the incongruous colour word they spell out (e.g. the word 'blue' written in red ink). Ozonoff and Jensen (1999) found that individuals with ASD do not show impairment on this task, suggesting that the interference of these two types of input information is not a particular problem. However, individuals with ASD show an interesting pattern of preserved and impaired performance in different conditions of a Go/No-Go task developed by Ozonoff, Strayer, McMahon and Filloux (1994) which was designed to test inhibition in ASD. In this task participants are presented with a circle and a triangle on a screen, and asked to respond in one of three ways. In a 'neutral' inhibition condition, participants are always required to respond 'go' to the same shape (circle or triangle). In a 'prepotent' inhibition condition, the participants 'go' stimulus is shifted to the opposite of the 'neutral' inhibition condition (e.g. from circle to triangle or vice versa). In the 'flexible' condition, the 'go' stimulus is determined randomly by a computer from trial to trial such that participants are required to shift from one response shape to the other, flexibly. The results from the study showed that although performance in the neutral conditions was not impaired in ASD, performance in the prepotent and cognitive flexibility conditions was impaired in relation to age, gender and IQ matched TD individuals. Thus the findings from this study suggest a specific difficulty in the inhibition of prepotent responses for individuals with ASD.

Although EF difficulties are readily demonstrable in individuals with ASD, there are some problems with the EF-deficit account. Executive functioning deficits are also found in clinical conditions other than ASD, for example, Attention Deficit Hyperactivity Disorder (ADHD), (Nyden, Gillberg, Hjelmquist & Heiman, 1999) an observation that limits the use of EF deficits as a diagnostic marker. In addition there are debates concerning the validity of the measures used to tap onto EF measures. Pennington and Ozonoff (1996) argue that EF tasks are complex, assessing many interacting component processes and capturing a wide range of *meaningful* variance, and it is not often possible to know which underlying cognitive components (which may not even be EF components), are responsible for the score. For example, poor performance on the WCST may be due to poor knowledge or salience of the category of 'number'. Similarly, poor performance on the Tower of Hanoi task may be due to poor spatial cognition rather than poor planning ability. It is also the case that the EF account focuses on explaining the repetitive and stereotyped behaviours and alone does not provide an adequate explanation for the other deficits observed in ASD, for example, the deficits in social interaction.

1.2.3 ToM Deficit Hypothesis

The ToM deficit hypothesis assumes that at the origin of the specific social impairment in ASD, is a neurologically based deficit in the ability to intuitively understand the mental states (such as beliefs) of other people, and a failure to attribute mental states both to self and to

others. This is thought to be a relatively automatic process for TD individuals. The theory is also referred to as 'mind blindness' or 'mentalising failure' (see Baron-Cohen, Spitz & Cross, 1993, 2000). The development of a ToM allows individuals to understand that other people's thoughts, beliefs and emotions can differ both from one's own, and from the actual state of reality (Premack & Woodruff, 1978). It also enables the understanding of complex concepts such as deception, pretence and irony and the prediction of behaviour in these contexts (Gopnik & Wellman, 1992).

The first study to investigate the ToM deficit in ASD used a false belief task with two dolls, Sally and Anne (Baron-Cohen, Leslie & Frith, 1985). In this task, children observed a doll named Sally place a marble in her basket. After Sally leaves the room, naughty Anne then moves Sally's marble from Sally's basket into her own box, whilst Sally has left the room. When Sally returns to the room and wants to play with her marble, children were asked where they thought Sally would look for it. Wimmer and Perner (1983) demonstrated that TD children, between the ages of 4 to 6 years develop the capacity to predict (or reason) that Sally will look in her basket because they understand that she (falsely) believes she put the marble in her basket (where she left it) and not Anne's box. However, in Baron-Cohen et al.'s (1985) study, only 20% of children with ASD answered correctly, despite also saying that Sally did not know the marble had been moved from her basket, which suggests that the children with ASD were not performing poorly on the task because of general intellectual disability or failure to remember the initial and final location of the marble. In comparison, 85% of children with Down-syndrome, who also had lower mental ages than the children with autism passed the test, as did 80% of TD children.

Besides understanding behaviour in terms of false beliefs, ToM also involves understanding the mental states underlying pretence, irony, non-literal language and deception. Individuals with ASD have been shown to experience difficulty with these (see Baron-Cohen, 1995). In addition they exhibit impairments in tasks in which they are asked to read a passage about a character in a story, and make a judgement about the normality of the character's behaviour. This is especially the case when an intuitive understanding of the motive of a character is needed in parallel with cause-and-effect reasoning about the story. For example, individuals with ASD have difficulty understanding that a burglar gave himself up to the police because he wrongly believed he had been caught, when in fact an animal broke the electronic detector beam and set off the burglar alarm (see Dewey, 1991; Happé, 1994a).

Although evidence of ToM difficulties is relatively robust in ASD, it is important to note that some individuals pass even very advanced ToM tasks. Bowler (1992), for instance, found that people with ASD could pass second order false belief tasks that can not be solved by inferring the mental state of one person (e.g., *John thinks*) but rather require the inference about

the relation between the mental states of two characters (e.g., *John thinks that Mary thinks*). More recently, tasks have been developed that measure a wider range of mental states and are more complex. For example, measures of ToM that have investigated the ability of individuals with ASD to read mental states from the eye region of faces alone, have also observed significant impairments in reading complex mental states (Baron-Cohen, Wheelwright & Joliffe, 1997). The impairments are observed alongside other measures which also continue to present difficulty for individuals with ASD, for example, the Strange Stories task (Happé, 1994a; Happé, Winner & Brownell, 1998) that requires individuals to identify complex mental states such as irony from narrative descriptions. This begs the question of whether it is mental state understanding or complexity that is difficult for individuals with ASD. Although some researchers argue against a specific ToM module (Bowler, Briskman, Gurvidi & Fornells-Ambrojo, 2005), advocated by (Leslie, 1987; Baron-Cohen 1995; Scholl & Leslie, 1999), the fact remains that people with ASD do experience difficulty with understanding mental states, which can account for some of the social impairment and withdrawal observed for these individuals. However, as the ToM deficit account is largely focused on explaining the social and communicative aspects of ASD, it can account less well for the perceptual processing differences and EF differences described above (see Frith & Hill, 2003).

Each of the three major psychologically-rooted theoretical explanations of ASD reviewed above highlights a subset of the behavioural facets of ASD. Although there is evidence to suggest that some difficulties are observed earlier than others, for example, that EF difficulties are observed earlier than ToM difficulties (Pellicano, 2010), no single explanation of ASD appears to be complete in itself. Instead of seeing them in competition with each other as *the* single explanation for ASD, they should instead be considered as complementary perspectives. Given that the social difficulties are among the most salient features of ASD, it is not surprising that ToM based explanations tended to dominate the field throughout the 1980s and 90s. Over the past two decades, however, the theoretical landscape has diversified and explanations such as the EF and WCC accounts have reached an equally influential status as ToM explanations of ASD. In addition, other theoretical strands have developed in a similar vein, including the idea that memory difficulties may constitute an important facet of the ASD phenotype.

Conclusions

It is recognised that an individual's memories are a result of previous experience and learning which informs our future behaviour, decisions, planning and imagining (Atance & O'Neill, 2005). For TD individuals, the ability to draw upon past experience to inform future decision making is crucial for daily functioning, and if this were to be disrupted it would result in numerous difficulties (as is the case for amnesics). The early phases of memory research in ASD noted the

parallels with the amnesic syndrome (the early work of Boucher & Warrington, 1976), however this research lessened because memory in high functioning individuals with ASD was not seen as a particular problem. However, more recent research into the memory difficulties of high functioning individuals with ASD has revealed a complex pattern of both memory strengths and weaknesses. Furthermore, cognitive theories have provided an interface between brain and behaviour to account for some of the core deficits and features of autism, uncovering faults (and strengths) in basic mechanisms of cognition. Memory in ASD has seen a surge of interest as researchers have begun to seek explanations for the patterns of behaviour observed for these individuals. Although ASD is not considered to be a direct result of atypical memory functioning (Boucher & Bowler, 2008), the unique patterning of behaviour can be better explained by appreciating the inner worlds of these individuals, gained from the study of their memory.

1.3 Memory in TD

"Memory is a function that permits animals and people to acquire, retain, and retrieve many different kinds of information… [and allows them]… to recognise the familiar, predict events, return to particular places, and assess the consequences of behaviour," (Sherry & Schacter, 1987, p. 439).

A long standing debate within memory research is whether memory phenomena can be conceived of as depending upon a single unitary system or multiple systems. For memory process theorists, memory is a single cognitive 'faculty' that operates according to certain processing principals (Gardiner, 2008). These principals are typically conceived of in terms of dichotomies, for example, Conceptual versus Perceptual, Item-specific versus Relational and Recollection versus Familiarity, which describe the manner in which a certain stimulus or event is processed. Memory systems theorists, on the other hand, argue that memory is more fruitfully conceptualised in terms of distinct sub-systems that can be classified and defined by a set of criteria such as the kind of information they deal with, their rules of operation (Gardiner, 2008) and the kinds of conscious states of awareness they give rise to (Sherry & Schacter, 1987). Research has tended to be divided between 'process' and 'systems' theories, however the two approaches can be seen as complementary and particularly in the context of ASD have significant heuristic value. Furthermore, both approaches permit the interpretation of scientific studies (using various tests of memory) within existing theoretical frameworks (see Gardiner, 2008).

One method of testing memory, which is particularly relevant to the work carried out in this thesis, is recognition. This generally refers to a procedure that assesses the ability to

successfully classify previously studied material into a category of 'Old' stimuli and novel stimuli (in the context of the experiment) into a category of 'New' stimuli. Recognition memory has been widely researched in both TD populations (see Yonelinas et al., 2002 for a review), and in ASD (see Bowler et al., 2007). In one recognition memory test procedure (the Remember/Know paradigm, see p. 62 for further detail), successfully classified studied material can be further subdivided by the subjective experience that characterises the instance of recognition. It is these idiosyncratic recognition experiences that are especially relevant for the work carried out in this thesis, and I will therefore focus the rest of this introduction on previous tests of recognition memory and their use in special populations such as ASD.

1.3.1 Memory Processes

According to Mandler (1991, 1980, 1979), (see Mandler, 2008 for a recent review) recognition memory judgements can be based on item *familiarity* or a *memory search* process referred to as *recollection*. According to this theory, familiarity and recollection are independent and operate in parallel, with familiarity being faster than recollection (Mandler, 1980). Familiarity serves as a process to integrate the perceptual aspects of an item into memory to support recognition and performance on implicit memory tasks. Recollection on the other hand, reflects a memory search process that supports recognition, but also performance on recall tasks. According to this model, recollection reflects a memory process in which elaborative information relating the event to its context and other events is retrieved.

Jacoby and colleagues (Jacoby, 1983, 1991; Whittlesea, Jacoby & Girard 1990; Jacoby, Jones & Dolan, 1998; McElree, Dolan & Jacoby, 1999) have conceptualised recognition memory slightly differently. Similar to Mandler, these authors argue that recognition is the result of two processes that are independent, but operate in parallel. However, rather than distinguishing between familiarity and recollection, they characterise one process as an automatic *fluency* process, that does not rely on the elaboration of stimuli on the basis of already existing memories. The second process is responsible for such elaboration of the item or its context during study and is assumed to be an analytic and consciously controlled process. To put this distinction in context, if one item is processed more fluently than another in a recognition memory test, individuals may unconsciously attribute this fluency to prior experience with that item, thus leading the participant to 'recognise' the item. Additionally, this process can also reflect the item's conceptual fluency (the meaning of the stimulus), which has been identified in studies showing its sensitivity to conceptual manipulations (Jacoby & Kelley, 1992). According to this account, both the fluency of the item and the elaboration of the item and/or its context are thought to rely on detailed memories for past experiences of the item.

Yet another model for characterising recognition memory is the model proposed by Yonelinas and colleagues (Yonalinas, 1994, 1997, 1999, 2001a, 2001b; Yonelinas, Dobbins, Szymanski, Dhaliwal & King, 1996; Yonelinas & Parks, 2007), which attempts to explain why recollection is usually associated with high confidence judgements whilst familiarity can be associated with confidence judgments that vary considerably. They argue that recollection reflects qualitative information, for which a judgement is made only after the information reaches a certain threshold. Accurate spatial and/or temporal information can be retrieved by the individual about the study event or item and lead to recollection of the details of a past episode in context, but occasionally the individual may fail to retrieve adequate qualitative information meaning the judgement does not reach the recollection threshold. For these judgements the individual makes a familiarity judgement, which is based on quantitative information about the 'strength' of the memory trace that is not sufficient to support memory for the associations between the elements of a past experience.

1.3.2 Memory Systems

Contrary to the conceptualisation of memory as a single system that is supported by a number of distinct *processes*, the classification of memory in terms of a number of interrelated yet distinct *systems* (Squire, 2004) provides a useful complementary heuristic for the study of memory. A number of different areas of experimental research have supported the non-unitary perspective of memory research, that is, that memory cannot be explained in terms of a single cognitive faculty. For example, neuropsychological data collected from individuals with acquired amnesia (Tulving, 2002; Cohen & Squire, 1980) and TD individuals (Rugg & Curran, 2007) have provided evidence for (at least partially) dissociable memory systems. In addition, experimentally induced (episodic/semantic) dissociations in memory performance with healthy TD individuals (Mintzer & Griffiths, 2003) have provided strong evidence for multiple memory systems. One approach to the study of memory, in which the complex nature has been highlighted, is that of *memory systems,* coined by Tulving (1985a), who defines memory systems as,

> "…the major subdivision of the overall organisation of the memory complex. They are organised structures of more elementary operating components. An operating component of a system consists of a neural substrate and its behavioural or cognitive correlates. Some components are shared by all systems, others are shared only by some, and still others are unique to individual systems." Tulving (1985a, p. 386).

According to Nadel (1992), the five separate but interacting human memory systems, each with separate subsystems, are; the procedural memory system, the perceptual

representation system, the working memory system, the semantic memory system and, the episodic memory system. The procedural and the perceptual representation system, share the features that they are considered non-declarative, non-conscious and implicit forms of memory, whilst the working memory system, semantic system and episodic system share the common attribute that they are open to consciousness, explicit and declarative memory systems, meaning they allow the cognitive registering of relations between objects and events (Tulving, 1985b). Briefly, the perceptual representation system differs from procedural memory in that it is believed to involve the representation of objects and events in their 'raw' perceptual form at a pre-semantic level. The procedural system is concerned with the memory for behavioural and cognitive skill, operating at an "automatic" level. The output of the system is non-cognitive and void of a truth value. This type of learning characteristically occurs though incremental stages and a gradual exposure to a repeated experience. The working memory system (Baddeley & Hitch, 1974) is different from the semantic and episodic memory systems in that it reflects a short-term, temporary storage for various types of information (e.g., auditory and visual information). This system is an extension of previous distinctions in memory made between short and long term stores (Atkinson & Shiffrin, 1968).

The episodic and semantic memory systems are the most developed of the five human memory systems because they are open to conscious awareness (Schacter & Tulving, 1994). The semantic and episodic memory systems share a number of different features, but the episodic system is argued to have grown out of the semantic system. Consequently, it is possible for the memory systems to be ordered in terms of how "advanced" they are. Within this framework, the more 'advanced' episodic memory system depends on, and is supported by the 'lower' semantic memory system, but possesses additional and unique capabilities to it. Semantic memory is the memory system responsible for timeless facts, such as the boiling point of water, whilst episodic memory is responsible for personally experienced and Remembered events that allow an individual to re-experience an event from the past.

According to Tulving (1983, 1985a, 2002, 2005), semantic memory allows the conscious experience of 'Knowing' in the absence of recollecting specific contextual details about the study episode. Episodic memory on the other hand, is concerned with the storage of personally experienced and unique events and allows 'Remembering'. Usually a Remembered episode is rooted within an individual's subjective time and space (Tulving, 1983), allowing the conscious re-experiencing of events from the past. Episodic memories, in this respect are considered "multifeature representations" of various kinds of information that are bound together by the individual (Schacter & Tulving, 1994, p.28). Performance on free recall tests are thought to rely heavily on the episodic memory system and therefore on Remembering, whilst performance in recognition tests are thought to rely equally on the episodic (Remembering) and semantic

(Knowing) memory systems. Importantly, participants in recognition paradigms have been shown to be able to reliably report instances of 'Remembering' and distinguish these from instances of 'Knowing', confirming not only that the two forms of memory are phenomenologically distinct but also that they can be dissociated through experimental manipulations (see Gardiner & Richardson-Klavehn, 2000 for a detailed discussion). Recognition tasks assessing this distinction are commonly referred to as 'Remember/Know' recognition paradigms.

According to Tulving (2001), encoding in the semantic and episodic memory systems is a serial process. That is to say, the episodic memory system is dependent upon information that is fed through the semantic memory system. This also means that information may be encoded into semantic memory without the use of the episodic memory system, but not the other way round. Storage of information, on the other hand, is parallel, so that past events can be stored in either the semantic or the episodic system or both systems concurrently. Lastly, given that an event is stored in both systems, it can be retrieved from either the semantic or episodic memory system independently.

Task procedures such as associative recognition tests (in which participants study pairs of items that are subsequently presented in preserved or re-combined pairs in a recognition test), measure a participant's ability to consciously retrieve associative or contextual information. During the test phase of associative recognition tasks, all studied items are equally 'old', meaning semantic recognition is of little use. Therefore for associative recognition (as opposed to item recognition), conscious recollection of the spatial and temporal context of the study episode (or episodic memory) is crucial. These tests have provided support for the notion of qualitatively distinct memory systems, as episodic and semantic memories differ in terms of their processing speed, semantic judgements being faster than episodic judgements (McElree, Dolan & Jacoby, 1999). Further evidence comes from patients with brain injury, for example, patients with acquired amnesia who show greater impairments on associative memory judgements compared to item recognition (Tulving, 2002; Aggleton, McMackin, Carpenter, Hornak, Kapur et al., 2000), implying that the regions of the brain which are damaged in amnesia play a larger role in associative memory processes relative to item recognition. In addition, neuropsychological data collected from individuals with acquired amnesia (Tulving, 2002; Cohen & Squire, 1980) and TD individuals (Rugg & Curran, 2007) provide evidence for distinct electrophysiological correlates for episodic 'Remember' and semantic 'Know' responses with the Remember/Know paradigm (Tulving, 2002). Event-related potentials (ERPs) have been shown to exhibit differing spatial scalp distributions and temporal windows during recognition tests for items that are successfully Remembered compared to those that are Known (Düzel, Yonelinas, Mangun, Heinze & Tulving., 1997; Yonelinas, Hopfinger, Buonocore, Kroll & Baynes, 2001).

1.3.3 Types of Conscious Awareness that characterise Episodic and Semantic Memory

One of the major features of the distinction between episodic and semantic memory, according to Tulving (2005) is that the two systems differ in the type of conscious awareness that characterises them. Semantic memory is characterised by *noetic* (knowing) consciousness, a type of consciousness that allows awareness of objects and events, as well as the awareness for the relations among them, in their absence. Flexible access to this kind of symbolic knowledge of the world can be accessed via storage and retrieval from the semantic memory system alone. Episodic memory, on the other hand is associated with *autonoetic* (self-knowing) conscious awareness. This type of awareness is necessary for an individual to Remember personally experienced events as part of their own past existence and to mentally re-live what was experienced in the past (Tulving, 1985b). Autonoetic conscious awareness is a special kind of consciousness that allows an individual to be aware of subjective time and to remember events from the past in a manner that Tulving (2005) likened to 'mental time travel'.

Autonoetic conscious awareness is *the* defining characteristic of the episodic memory system. Early conceptualisations of episodic memory were made on the basis of the type of information the system was thought to store (Tulving 1972), for example, the 'what', 'where' and 'when' of memories (what happened, where it happened and when it happened). However, this information alone is insufficient to ascribe mental time travel (which is stipulated for more current definitions of autonoetic consciousness, Tulving, 2002, 2005). For example, it is possible to know exactly what happened, where you were and when you spoke your first word, without Remembering the actual event. Similarly, various food-storing animals, for example scrub jays, have demonstrated adapted food caching and retrieval strategies depending on the expiry and decay of their cached food, i.e., they choose to search for a particular perishable cache when fresh and not when perished (Clayton & Dickinson, 1998). As information about each caching experience is unique, these studies seem to imply that these animals are sensitive to the spatial and temporal dynamics of their own past events and by earlier definitions (Tulving, 1972), are capable of having episodic memories (i.e., able to store and retrieve information about temporarily dated events, and the temporal–spatial relations among events). However, Clayton and Dickinson's (1998) findings do not provide evidence for autonoetic conscious awareness by current definitions, as they do not demonstrate the animals' ability to consciously experience the self, 'mentally' travelling back in time to remember where they have cached the food. What they do demonstrate is the ability to know the 'what', 'where' and 'when' of their past. Tulving (2002, 2005), has highlighted the importance of the autonoetic consciousness of retrieval, and the ability to engage in mental time-travel through subjective time – past, present and future. Tulving (2005)

argues that mental time travel allows the owner of the episodic memory to travel through the medium of autonoetic conscious awareness to remember previously thought about experiences.

Episodic memory is an ability that is thought to be unique to humans (Suddendorf & Corballis, 2007; Tulving & Markowitsch, 1998). The findings implicating episodic memories in non-human animal research have therefore appropriately been termed episodic-like memory (Clayton & Dickinson, 1998; Clayton & Russell, 2009). Further, Suddendorf & Corbalis (2007) argue that because animals lack the conceptual abilities needed for episodic recall, episodic-like memories should be called 'semantic' (see also Dere, Huston & Silvia, 2005; Hampton, Hampstead & Murray, 2005). For example, the scrub jays just *know* what was hidden, where and when as opposed to *re-experiencing* caching the food.

Whether or not a non-human animal is capable of episodic remembering, and by which definitions it is capable of doing so, is important for informing future research and the development of our understanding of episodic memory in ASD as well as TD individuals, particularly with respect to the assessment of memory in young and non-verbal children. However, in the context of studies reported here, this debate is beyond the scope of this thesis. Furthermore, as the present research was conducted exclusively on human participants, the elaborative description of episodic memory and autonoetic conscious awareness provided by Tulving (2005, see also Suddendorf & Corballis, 2007) were used here, as these capture additional features of human episodic memory, crucial for the work carried out in this thesis (i.e., mental time travel).

From an evolutionary perspective, as information about past experiences can be retrieved independently of autonoetic conscious awareness, it is important to consider reasons for the existence of such a system. A possible evolutionary gain for such a system is highlighted by increased confidence ratings for 'Remember' responses (Tulving, 1985b). That is, 'Remember' responses are associated with increased subjective certainty and a greater willingness to act. Consequently, recognition without recollection may seem somewhat more like guessing compared to when the spatial and temporal context of a memory is available. For this reason, autonoetic conscious awareness has profound implications for the decisions made by an individual at the moment of retrieval, the effectiveness of their planning for future events and the ability to foresee the consequences of personal decisions. Thus, the evidence outlined above distinguishes between autonoetic conscious awareness and noetic awareness on numerous grounds. They differ in the type of information they store, the type of conscious awareness they are associated with and the degree of subjective certainty that characterises them.

Summary

Although all three memory process accounts assume that recollection and familiarity function independently at retrieval; they differ with respect to how familiarity is described. For example, Mandler's original model adopts the assumption that recollection and familiarity are reflections of conceptual and perceptual memory processes respectively, whereas Jacoby's model explains familiarity as a process that reflects both conceptual and perceptual fluency. Process theories are useful for the investigation of memory and have been widely applied to the study of memory in TD. Conversely, virtually the entirety of episodic/semantic memory research conducted on individuals with ASD has adopted a memory systems view. Therefore, to remain consistent with the memory research in ASD (and to reflect the episodic/semantic bias in ASD literature) as well as memory research in TD, a memory systems view will be favoured for the purpose of the research carried out in this thesis.

1.4 Memory in ASD

Although an exhaustive review of the findings and theories of memory performance in ASD is beyond the scope of this thesis (see Boucher & Bowler, 2008), the main conceptualisations of memory in ASD will now be summarised. Episodic and semantic memory performance in ASD will be reviewed in further detail as they are relevant to the research carried out in this thesis.

1.4.1 Failure to Encode Stimuli Meaningfully

The earliest clinical accounts by Kanner (1943) and Asperger (1944/1991) noted the good rote memory performance of individuals with ASD and gave rise to a widely held view that memory, and the capacity for a general memory storage system was not impaired in ASD. However a capacity for a good rote memory implies a functional memory span but not necessarily memory functioning that is entirely preserved. Early accounts of memory in ASD noted that individuals failed to use structure or semantic information in a meaningful way to facilitate later memory performance (Hermelin & O' Connor, 1970). In an early study, Hermelin and O'Connor (1970) compared the recall of sentences versus unrelated word lists (of same length as the sentences) in a group of children with and without ASD, matched on digit span. The TD children were better able to recall the sentences compared to the unrelated word lists, however this pattern was not found for children with ASD. These findings led the authors to suggest that information is not encoded and used meaningfully for individuals with ASD. The findings have been consistently replicated for individuals with low functioning ASD (Fyffe & Prior,

1978).

High functioning individuals also demonstrate impairments using semantic information to aid recall, for example, Bowler, Matthews and Gardiner (1997) demonstrated, using categorised (stimuli from the same category e.g., fruit) versus uncategorised word lists, that TD individuals were able to use the category information to aid subsequent recall whereas individuals with ASD failed to use this information. More recent research suggests that this may be an overstatement, and that individuals with ASD are, in fact, sensitive to the semantic relations amongst to-be-remembered words, as they demonstrate susceptibility to illusory memories (associatively related but non-studied words) when tested with the Deese, Roediger and McDermott (DRM) procedure (Deese, 1959; Roediger & McDermot, 1995). In this procedure participants are asked to recall a list of words (bed, rest, awake) that are strongly associated with another non-presented word (sleep). On subsequent tests of recall or recognition, participants often falsely remember this non-presented word. Individuals with ASD have been shown to be susceptible to such memory Illusions (Bowler, Gardiner, Grice & Saavalainen, 2000b; Kamio & Toichi, 2007; Hillier, Campbell, Keillor, Phillips & Beversdorf, 2007) suggesting that sensitivity to semantic relations may be diminished but not completely absent in ASD (Bowler, 2007).

1.4.2 Complexity Account

Minshew, Muenz, Goldstein and Payton (1992), argue that the memory of individuals with ASD becomes increasingly impaired as the complexity of material increases. Minshew and Goldstein (1998) argue that the memory impairments observed for individuals with ASD are due to specific abnormalities in the processing of complex information. To assess the dynamic concept that is *complexity* (which is largely relative to the age and general level of ability of the individual being tested), a standard battery of tests for both auditory and visual modalities was used, the Wechsler Memory Scale - Third Edition (WMS-III, Wechsler, 1997). HFA adolescents and adults have demonstrated similar patterns of performance for auditory and visual memory performance using the WMS-III. Minshew and Goldstein (2001) have demonstrated that although ASD individuals show similar levels of performance to TD individuals on basic measures of attention and associative memory, the cognitive-mediating processes (e.g. category clustering and other organisational strategies) used to support memory on such tasks were impaired. Furthermore in their study, memory impairments (observed in both auditory and visual modalities) were progressively worse as the complexity of the material increased. Memory for social scenes and faces also posed difficulty for ASD individuals, which the authors suggested may be due to the high information processing demands of these stimuli. On the basis of these findings, Minshew and colleagues put forward the idea that the patterning of memory observed in

individuals with ASD results from a general deficit in the processing of complex information. However the complexity account begs the question of what the tasks that are described as 'complex' actually entail. It therefore invites recurring explanations for the impairments observed by labelling tasks as 'too complex' and necessitates other ways of looking at memory in ASD (Bowler, 2007).

1.4.3 Task Support Hypothesis

Individuals with ASD show contrasting performance in tasks such as cued recall versus free recall. On cued recall tasks, where support is provided at test in the form of a cue, individuals with ASD do not show impaired performance, however in free recall tasks they often do (Boucher & Warrington, 1976), especially when success on the task requires an awareness of the semantic relations among studied items (Bowler et al, 1997; see Tager-Flusberg, 1991). Although first noted by Boucher and Warrington (1976), this pattern of spared and impaired memory performance has been developed by Bowler and Gardiner into the *Task-Support Hypothesis* (TSH), (Bowler et al., 1997; 2004), which states that the performance of individuals with ASD will be comparable to that of TD individuals if support is provided at test. Support can be provided by any information relevant to the resolution of the task being present, this includes cued recall and recognition memory tests where participants are presented with a clue (the studied word) and are asked if it was presented. In contrast, tasks such as free recall and generation[1] do not offer this kind of support, and show impairment in individuals with ASD.

Support for the TSH has been provided by numerous subsequent studies that have confirmed the observation that support at test enhances memory performance of individuals with ASD. In one example, Bowler, Gaigg and Gardiner (2008b) tested the effects of item versus context relatedness on recall and recognition in adults with ASD by asking individuals to study a series of words presented on a screen, inside a red rectangle. Participants were asked to ignore context words (words that were either related or unrelated to the study words) that were presented outside the red rectangle. Participants then took part in a forced-choice recognition memory test which revealed that both groups recognised more target words than context words, and more related words than unrelated words. However despite this apparent spared memory performance, when the experiment was repeated with a recall rather than forced choice task, the

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[1] Examples of generativity tasks include generating novel ways to use objects, generating exemplars of a category or generating words beginning with a specified letter. Difficulties with these types of tasks have been demonstrated with individuals with high functioning ASD (Turner, 1999a, b).

recall of individuals with ASD was not enhanced for related words. These findings suggest that the relations between the target and context words were encoded (enough to benefit recognition in a forced choice recognition procedure), but this encoding was not of any significant benefit when memory was tested with a free recall procedure. As predicted, individuals with ASD showed a greater difficulty in the free recall task, where little support for retrieval was provided. Evidence to elucidate the nature of 'support' in the Task Support Hypothesis has been provided by two further studies which have suggested that merely providing clues to the studied material and giving instructions to participants is not enough to stipulate 'task support'. TD individuals show enhanced recall of items from categories when asked to sort items at study (Hunt & Seta, 1984). Smith, Gardiner and Bowler (2007) trained participants in how to make use of semantic and phonemic relations amongst word lists and found no enhancement in recall performance for individuals with ASD suggesting that instructing participants in this way did not provision task support. Contrastingly, in a study by Gaigg, Gardiner and Bowler (2008) individuals with ASD were actively involved with the list by asking them to concentrate on the relational aspects of the material (higher order categories rather than their pleasantness as in Hunt & Seta's study). In this task recall was also enhanced for the ASD group, showing that rather than lacking the ability to process relational information to aid recall, the ASD group experience difficulty when spontaneously recruiting these abilities to support learning and memory in new and unsupported situations (Gaigg et al., 2008). A question that the Task Support Hypothesis leaves unanswered is what causes the disproportionate need for support in ASD and this issue has been addressed with a further conceptual distinction that will form the focus of the next section, the distinction between relational and item-specific information processing.

1.4.4 Relational Processing

Rather than being exclusively an encoding problem for individuals with ASD, studies of semantic cued recall have suggested that individuals with ASD fail to use semantic relations to aid recall. For example, studies that have investigated the propensity for illusory memories in ASD have supported the notion that semantic or associative relations are in fact encoded in ASD (contrary to the earlier suggestion made by Hermelin & O'Connor, 1970). The DRM paradigm (see p. 31) has been especially useful for this account of a retrieval, rather than encoding failure of semantic associations in ASD. As we have already seen, false recognition in ASD follows a similar pattern to that seen in TD (Bowler et al., 2000b; Kamio & Toichi, 2007) suggesting that to some extent the meaning and associative nature of the study lists of words is encoded.

Bowler, Gaigg and Gardiner (2009) and Gaigg et al. (2008), have suggested that one possible explanation for the observations of memory in ASD can be sought from the underlying

structure of the tasks typically used in experimental paradigms, and have drawn upon a distinction between item-specific and relational processing. Individuals with ASD have been shown to engage in an item-specific processing style, on a to-be-remembered list (Bowler et al., 2009), which involves a less complex level of memory awareness compared to that involved in the processing of hierarchically organised categories. Hierarchically organised categories on the other hand, typically favour a relational processing style (relational-complexity, Halford, 1993) which makes use of how inter-item relations link with higher order categories. Individuals with ASD are less likely to engage in a relational style of processing (Bowler et al., 2009), suggesting that they experience greater difficulty than TD individuals when relating studied items to a hierarchically organised framework of knowledge. Hierarchical organisation also implies flexibility, for example, awareness that the word 'apple' is related to 'pear' but also to 'fruit'. An awareness of this latter relation also suggests awareness that 'apple' is related to 'pomegranate' and implies flexibility. Flexible access to this kind of knowledge is crucial for episodic memory.

The results from these studies suggest that the associative relations and information about the 'meaning' of studied information is less efficiently utilised in recall tasks for individuals with ASD (Bowler et al., 2008b). This suggests that although some aspects of meaning related information are encoded (evidence for which comes from the memory illusion task described above), it is not always to the benefit of free recall, leading to the conclusion that individuals with ASD do not benefit from categorical information to the same extent as TD individuals (Boucher & Bowler, 2008).

Relational Processing impairments in ASD have also been demonstrated with memory for multiple features of stimuli. According to Chalfonte and Johnson (1996), Relational Processing requires the binding together of combinations of features, or the elements of an episode (for example, place, objects, time of day, weather etcetera). Individuals with ASD have been shown to experience difficulties with binding together elements of stimuli in memory (Bowler, Gaigg & Gardiner, 2008a). In this study, Bowler and colleagues (using a procedure first used by Chalfonte & Johnson, 1996 with typically aging individuals), asked individuals with ASD to study grids of items, where items were presented in non-canonical colours (e.g., a blue banana). At test, recognition for features of items alone (item, colour or their location), as well as combinations of features (item and colour, or, item and location), was tested. The findings of this study demonstrated that the ASD group had no difficulties with the recognition of single features but showed diminished recognition of "episodically-defined" or multi-feature combinations, providing support for Relational Processing impairment for individuals with ASD.

To summarise, these studies demonstrate that individuals with ASD do not experience difficulties with item-specific processing but show diminished relational processing. This explains

the observed pattern of a lack of flexibility in memory in ASD, as evidenced by diminished use of semantic associations to aid free recall (Heremelin & O'Connor, 1970). Diminished flexibility also has repercussions on episodic memory, where elements have to be bound into episodically defined units (see Chalfonte & Johnson, 1996). Individuals with ASD have been shown to demonstrate difficulties with episodic memory, which involves processing information *in relation to* spatial and temporal context of a memory (considered to be multi-feature representations).

In parallel with the psychological and behavioural work described above, other explanations of ASD have also been proposed. These include suggestions such as abnormal brain development and atypical neural systems in ASD. These investigations have used methods such as functional Magnetic Resonance Imaging (fMRI) and electroencephalography (EEG). In brief, fMRI allows the blood flow to functioning regions of the brain to be registered and recorded in an image. EEG is the measurement of electrical potentials in the neurons of the brain as a participant completes a task. Additionally, EEG can be recorded 'online' meaning the recording is taken as the participant completes the experimental task. The recording can be time-locked to a specific event in the experimental paradigm, and is then called an Event Related brain Potential (ERP). This thesis will concentrate on EEG and ERPs (see Chapter 2), however in order to consider the more general aspects of the brain the next section of the thesis reviews research that has put forward a brain basis of ASD. The potential implications of this for the EEG of individuals with ASD will be addressed.

1.5 Models of the Brain Bases of ASD

1.5.1 Brain Development in ASD

Evidence collected from MRI, head circumference data, and post-mortem studies suggest that there is an atypically rapid pattern of early brain growth before 2 years of age in ASD (Redcay and Courchesne, 2005) which then asymptotes between 2-4 years. It has been suggested that the rapid early overgrowth contributes to atypical development of connectivity in the cortex. This is particularly apparent in the frontal lobes where synaptic connectivity patterns take longest to mature and the timing overlaps with that of synaptogenesis, apoptosis and myelination in typical development (Courchesne and Pierce, 2005). This difference in 'structural' connectivity is hypothesised to have implications for 'functional' connectivity (the temporal relationship between two or more synchronously active neuronal assemblies, see Friston, 2004) between ASD and TD individuals.

Barnea-Goraly, Kwon, Menon, Eliez, Lotspeich and Reiss (2004) have applied Diffusion Tensor Imaging (DTI), which is a technique that measures the differential diffusion of water molecules in the direction of myelinated pathways) to the study of ASD. This method can be

especially useful for confirming a priori assumptions about connectivity in the human brain and can be correlated with performance in populations with cognitive dysfunction, such as developmental dyslexia (see Beaulieu, Plewes, Paulson, Roy, Snook, Concha and Phillips, 2005). DTI investigations have also been useful to identify atypicalities in myelin integrity in ASD. For example, Barnea-Goraly et al. (2004) have reported reduced myelin integrity in ventromedial prefrontal cortex, anterior cingulate and temporoparietal junctions in individuals with ASD. These areas are involved in aspects of social cognition such as theory of mind tasks, which is significant in the study of ASD (Rippon, Brock, Brown and Boucher, 2006). It has been suggested that the disturbance in the normal developmental time scale in ASD described above, impairs the cortico-cortical and coritco-cerebellar connections, resulting in under-connectivity between certain key areas of the brain (Courchesne and Pierce, 2005). Rippon et al. (2006) propose that this may provide tentative evidence for long-distance structural under-connectivity in ASD. Evidence for atypicalities in connections amongst distributed neural systems in ASD is also apparent in decreased correlations of cerebral blood flow and metabolism (Just, Cherkassky, Keller and Minshew, 2006) as well as MRI studies which have suggested increased white matter in ASD individuals (Herbert, Zielger, Makris, Filipek, Kemper, Normandin et al., 2004).

EEG recordings (although lacking the spatial resolution of MRI based techniques such as DTI) directly relate to the dynamic postsynaptic activity in the cortex (see Chapter 2). The synchronisation of neuronal populations therefore can be estimated from EEG recordings using coherence measurements between two or more spatially distributed neuronal assemblies. High coherence between two EEG signals reflects synchronised neural oscillations and functional integration, and low coherence reflects independently active neuronal assemblies and independent populations or functional segregation (Murias, Webb, Greenson, Dawson, 2006). EEG coherence measurements are thought to reflect functional cortical connectivity on a centimetre scale (Nunez and Srinivasan, 2006) directly, via cortico-cortical fibre systems, or indirectly via cortical or sub-cortical networks. ASD appears to be associated with abnormalities in connections among distributed neural systems. Empirical support for reduced connectivity in ASD comes from findings of increased cell dispersion and reduced sizes of cortical minicolumns in brains of individuals with ASD and fMRI studies showing reduced functional connectivity during complex tasks. Murias et al. (2006) have assessed functional connectivity in ASD using EEG coherence methods, and found robust contrasting patterns of over- and under-connectivity at distinct spatial and temporal scales. In the delta and theta (2-6 Hz) frequency range, individuals with ASD showed locally elevated coherence, especially within left hemisphere temporal and frontal regions. In the lower alpha range (8-10 Hz), the ASD group showed globally reduced EEG coherence within frontal regions, and between frontal and all other scalp regions. In conclusion, the evidence suggests that the frontal lobes in ASD are poorly connected with the

rest of the cortex in this frequency range. These group differences in frontal lobe connectivity may underpin anomalies in frontal ERPs we observe in ASD, and should be taken into consideration alongside interpretation of frontal ERP data.

A further suggestion for a brain basis of ASD includes the postulation that ASD results from an excitation/inhibition imbalance in neural systems for the brain of individuals with ASD. The next section of the thesis reviews this model of ASD.

1.5.2 Excitation/Inhibition Imbalance in Neural Systems in ASD

Linkage analyses suggest that there are multiple genetic loci that contribute to the expression of ASD (Risch, Spiker, Lotspeich, Nouri, Hinds, Hallmayer, et al., 1999). It is likely that the heterogeneity of the expression of ASD relates to the heterogeneity of the genetic factors that underlie the disorder (Rubenstein and Merzenich, 2003). The evidence relating to genetic abnormalities that are associated with ASD as well as the advances in understanding the neural systems that process sensory information, memory and social and emotional behaviours has led Rubenstein and Merzenich to posit a model which postulates that the cortex and other key neural systems of individuals with ASD might be characterised by an imbalance between excitation and inhibition, leading to hyper-excitability and unstable activity in cortical networks following typical sensory stimulation (see Hussman, 2001; Rubenstein and Merzenich, 2003; Belmonte et al., 2004; Polleux and Lauder, 2004). The model argues that the increased ratio of excitation/inhibition in ASD is caused by a combination of both genetic and environmental variables that play a role on the functioning of a given neural system.

Rubenstein and Merzenich (2003) suggest that at least some forms of ASD are caused by disproportionately high levels of excitation or, weak inhibition in neural circuits that are thought to specifically mediate language and social behaviours. These defective neural systems by nature are more poorly functionally differentiated, which leads to broad ranging abnormalities in perception, memory and cognition (referred to as the 'noisy' cortex). The suggestion postulated by these authors has important implications on the current research, as a 'noisy' cortex will undoubtedly affect the quality of the ERP measures gathered. It is also possible that these defective neural systems may affect group differences in ERP measures i.e., increase variability and obscure group differences, or, exaggerate them depending on the measures chosen to analyse data (for example, mean voltage amplitude versus peak amplitude, see section 2.3 for a discussion). In conjunction with a careful consideration of the methods chosen to analyse ERP data, the size of the standard deviations for the ASD and TD groups should be taken into consideration alongside any interpretations (see Section 8.7.1 for the implications for the current set of experiments).

Despite the processing caveats, ERPs have been particularly useful for investigating

aspects of memory where individuals with ASD show behavioural differences compared to TD individuals, for example, episodic memory. The next section of this thesis reviews the evidence relating to a diminished episodic memory in ASD. Following this, the evidence relating the episodic and semantic memory systems to particular brain structures in TD individuals is discussed. Last, the ERP correlates of episodic and semantic memory are described as these are most relevant for the current research.

1.6 Episodic Memory in ASD

In general, individuals with ASD demonstrate poor free recall (Smith et al., 2007; Boucher & Warrington, 1976), significantly diminished memory for personally experienced events (Bruck, London, Landa & Goodman, 2007; Crane & Goddard, 2008; Tanweer, Rathbone & Souchay, 2010) and poor source memory (Lind & Bowler, 2009b; Russell & Jarrold, 1999). Each of these tasks points towards atypicalities in the Episodic memory system in ASD (Wheeler, Stuss & Tulving, 1997), which has recently also been supported by studies of episodic future thinking (Lind & Bowler, 2010). Recalling past episodes and imagining specific future events has been shown to rely on overlapping processes (see D'Argembeau, Raffard & Van der Linden, 2008; Spreng, Mar & Kim, 2009), which Lind and Bowler (2010) probed by requiring individuals to recall past events and to report a series of events that might happen to them in the future. Individuals with ASD in this study imagined and recalled fewer specific events compared to matched TD individuals, confirming previous reports of impaired episodic memory in ASD and extending these to the domain of episodic future thinking. Of particular relevance to the current thesis are findings of reduced Episodic 'Remembering' for past events in studies that have employed the Remember/Know recognition paradigm (Bowler, Gardiner & Grice, 2000a; Bowler et al., 2007). Specifically, these studies have shown impairments in episodic 'Remembering' in ASD, which seems to be compensated by an increase in semantic 'Knowing' such that recognition memory overall is unimpaired (at least in high functioning ASD individuals).

Although the above evidence points to episodic memory difficulties in ASD, it does not clarify whether the atypicality in this domain is quantitative or qualitative in nature. In other words, it is not clear whether the phenomenological experiences of autonoetic conscious awareness that characterises episodic memory in ASD is similar to TD individuals. To elucidate whether the residual Remember responses made by individuals with ASD had the same experiential quality as (i.e., are qualitatively similar to) TD individuals, Bowler et al. (2007) have drawn upon a series of manipulations known to have differential effects on Remembering and Knowing in TD individuals. The first manipulation drew upon Gardiner and Parkin's (1990) finding that Remember responses are diminished and Know judgements are preserved in TD individuals when attention is divided at study. Participants were asked to study a series of words on a

computer screen either under a full attention condition (i.e., no distractions) or a divided attention condition where participants studied the word list whilst labelling randomly occurring auditory tones as high, medium or low in pitch. At test individuals provided Remember/Know judgements for recognised items and as expected, individuals with ASD showed diminished episodic Remember judgements relative to the comparison group. Importantly, however, both groups exhibited a greater reduction in Remember than Know judgements in the divided as compared to the full attention condition suggesting that although the quantity of episodic Remember judgements was reduced in ASD, they share the same qualitative experience as TD individuals.

In a second manipulation, Bowler and colleagues drew upon Gregg and Gardiner's (1994) finding that same versus different study-test modality (e.g., visual versus auditory presentation) selectively modulates Know judgements but leaves Remember judgements unchanged. As this manipulation has been found only to impact Know judgements, the authors argued that any difference in Remember judgements for the ASD group would suggest qualitative differences in ASD (possibly mislabelled Know responses). The findings replicated those of Gregg and Gardiner (1994) and showed that for the ASD and comparison group, employing an auditory modality at test when words were studied in a visual modality decreased the number of Know judgements relative to when test words were presented in the visual modality (the same mode as study). Crucially, Know judgements decreased in the ASD group as predicted by Gregg and Gardiner's finding in TD individuals, providing further evidence to suggest qualitative similarities for both groups.

In a study by Dewhirst and Hitch (1997, also see Wallace, Stewart, Sherman & Mellor, 1995) it was found using a lexical decision task, that false identification was more likely for a late phoneme change ('paradife') than early phoneme change ('faradise', for the word 'paradise'), and that this manipulation selectively increased Know judgements in TD individuals. Their results showed that the representation of the non-studied word (paradise) was an implicit process (as it occurred for Know judgements). Bowler and colleagues replicated Dewhurst and Hitch's (1997) procedure and confirmed that the late phoneme change resulted in more false recognitions of the 'Know' type than early phoneme changes in both TD and ASD groups. Dewhurst and Hitch also identified that when items were presented three times, Remember responses selectively increased relative to a single presentation. Bowler et al., (2007) confirmed and extended this finding in ASD. The results suggest that the manipulations used to selectively modulate Remember and Know judgements in the comparison group, modulated the ASD group's responses similarly, and provide additional support for the argument that experiences of Remembering and Knowing are qualitatively similar between groups. Episodic Remembering appears to be possible, but less common in this population.

1.6.1 Why is Episodic Memory Diminished in ASD?

The evidence presented above suggests that the episodic memory system is partially intact in individuals with ASD. On the one hand, they are able to successfully recall the spatial and temporal context of their memories and engage in 'mental time travel' (Tulving, 2002), however they appear to do this less often than typically developing comparison participants. Although the quantity of episodic memory judgements are diminished the experience of autonoetic conscious awareness and Remembering may be preserved, but the question of why episodic memory is diminished in ASD remains to be explained. Episodic memory has at least two components. One component involves the ability to re-construct the spatial-temporal context of the episode. The other component involves a sense of self awareness at the heart of the episode and a sense of the temporal nature of a stream of events, in other words a sense of continuity between the current self and the self at the heart of the reconstructed episode.

An understanding that events from the past involve the same self as the self I experience now (a sense of self awareness) and, an understanding that events can take place at different times (a sense of the temporal stream of events) are crucial for episodic Remembering (Hoerl, 2001; Hoerl & McCormack, 2001; McCormack, 2001; McCormack & Hoerl, 1999, see Bowler & Gaigg, 2008). With this in mind, it can be argued that a diminished episodic memory system in ASD, may result from an impairment in either (or both) of these processes.

The first requirement of episodic Remembering is a sense of self awareness. According to Neisser (1988) there are five kinds of self awareness; the ecological, interpersonal, conceptual, private and temporally extended sense of self. Individuals with ASD demonstrate preserved ecological self awareness through intact awareness of their own bodies in relation to the environment (Williams & Happé, 2009), however they are less interpersonally aware of themselves in relation to other people (Hobson, 1993) which may arise because of impoverished social interaction in ASD during early development (Lind & Bowler, 2008). Ecological and interpersonal self awareness (together constitute implicit self awareness and) are perceptually based. Conceptual, private and temporally extended self awareness are representational and develop later than implicit self awareness. Conceptual self awareness is a set of beliefs about the self (the 'me'). Although individuals show preserved ecologically grounded components of conceptual self awareness (for example, mirror self-recognition, Dawson & McKissick, 1984) they demonstrate impairments in interpersonally grounded components of conceptual self awareness, for example, personal responsibility, normative standards, and the role of audience (Capps, Yirmiya & Sigman, 1992). Private self awareness involves the understanding and conceptualisation of one's own mental states which are not accessible to others. Individuals with ASD show impairment in this domain often claiming unintended actions were intended (Phillips,

Baron-Cohen & Rutter, 1998). This impairment also extends to the understanding of own emotional states (Ben Shalom, Mostofsky, Hazlett, Goldberg, & Landa et al., 2006). Lastly, temporally extended self awareness allows individuals to experience a sense of personal continuity through time, impairments in which have been reported in individuals with ASD in delayed self recognition tasks (Lind & Bowler, 2009).

Impairments in conceptual, private and temporally extended self awareness are likely to contribute to impaired episodic memory in ASD (Lind & Bowler, 2008), as an understanding that events can take place at different times is clearly linked to the development of private and temporally extended self awareness, which are atypical in ASD. However, in addition to a functioning sense of self awareness, episodic memory requires the understanding of the temporal order of strings of events, in which individuals with ASD have also shown diminished ability. For example, in the Corsi Blocks Task (where participants are asked to tap a sequence of blocks of varying lengths, in the same sequential order as demonstrated by an experimenter) individuals with ASD show diminished performance (Bennetto, Penington & Rogers, 1996). Similarly, verbal tests of serial recall have shown that individuals with ASD are impaired at reproducing a sequence of words or digits in the correct order, despite the fact that their memory for the words themselves is preserved (Poirier, Martin, Gaigg & Bowler, *in press*). Thus, it seems that both an impoverished awareness of 'self' as well as difficulties in re-constructing the spatial-temporal context of previous experiences contribute to diminished episodic memory in ASD.

In considering the causes of episodic memory impairments in ASD, it is important to not only consider abnormalities in constituent processes as a possible source of difficulty, but also abnormalities in the development of these processes, and the system as a whole. Episodic memory does not emerge in TD children until about four years of age, the same age as children start to understand the representational nature of mental states in others (i.e., Theory of Mind, Wimmer and Perner, 1983). According to Perner (2000) metarepresentational abilities such as those involved in ToM, enable not only an understanding of false belief and other mental states but also facilitate episodic Remembering. This view has been supported by empirical evidence (Perner and Ruffman, 1995) using a series of different 'seeing-leads-to-knowing tests'. These tests examine a child's ability to provide reasons for their knowledge or ignorance of some fact, for example, in situations where the experimenter manipulates how much perceptual access the child has to an object in question (after observing an object being put into a box children might be asked to provide a reason for their knowledge of what is inside). Perner and Ruffman's (1995) findings suggested that before the age of four years, children cannot reflect on the perceptual origin of their knowledge as they have insufficient understanding of what constitutes experience. According to Perner and Ruffman, it is between the ages of about three and six years that children develop the ability to encode events as experienced and therefore develop the capacity

for 'Remembering'. From this perspective, impaired performance on Theory of Mind tasks such false belief tasks (Perner and Wimmer, 1985) would suggest an impaired episodic memory. This suggestion would account for the co-occurrence of episodic and Theory of Mind impairments in ASD.

So far, this chapter has introduced three theoretical accounts of ASD; the 'Theory of Mind Deficit' hypothesis, the Weak Central Coherence account and Executive Functioning account. The evidence relating to a fourth theoretical account of ASD, a diminished Episodic memory was also reviewed. More specifically, it is suggested that autonoetic conscious awareness that defines episodic memory is quantitatively attenuated but qualitatively preserved in ASD, whilst reliance upon the semantic memory system (associated with noetic awareness) is preserved or even enhanced. This conclusion is supported by behavioural evidence from 'Remember/Know' recognition paradigms, which show that experimental manipulations that are known to influence Remember and Know judgements differentially in TD, do so similarly in ASD. Although this evidence suggests that abnormalities in episodic memory in ASD are quantitative rather than qualitative it is nevertheless possible that different underlying neural processes mediate episodic and semantic memory experiences in ASD.

The electrical brain activity associated with the aspects of memory that function atypically in ASD has been extensively researched in TD individuals, revealing temporally and topographically distinct patterns of brain-based electrical activity. Such activity patterns have yet to be explored in ASD, hence the main aim of the empirical work reported in this thesis, was to explore the electrophysiological brain correlates of episodic and semantic memory in ASD, in order to inform us about the nature of the memory deficits observed in this subgroup of the population. The next section of the thesis reviews the brain bases of the episodic and semantic memory systems and following that, section 1.8 reviews the ERP correlates of episodic and semantic memory in TD individuals.

1.7 Brain Bases of the Episodic and Semantic Memory Systems

Evidence gathered from multiple methodological approaches such as brain lesion studies, imaging studies and animal studies, has suggested that it is the Medial Temporal Lobe (MTL) that serves episodic and semantic memory (Eichenbaum, Yonelinas and Ranganath, 2007). Several studies have also suggested that the frontal and parietal structures may play an important role in memory functioning (see Aggleton and Brown, 1999). The next section of this thesis outlines the anatomical structure of the MTL and the models of the brain bases of different memory systems. Evidence gathered using methodologies other than ERPs are discussed to consider alternative literature on the brain bases of the different memory systems and the

possible neural generators of the ERP Old-New effects that are relevant for the work carried out in the current thesis.

The anatomical sub-regions of the MTL in humans and monkeys are divided into parahippocampal cortex (which is further subdivided into the perirhinal cortex, parahippocampal cortex and entorhinal cortex), and the hippocampus (including the dentate gyrus, Ammon's horn and subiculim). Input to the perirhinal cortex mostly comes from the association areas that process unimodal sensory information ('what') and projects to the lateral entorhinal areas. Input to the parahippocampal comes from areas that process multimodal spatial information (e.g., 'where') and projects to the medial entorhinal areas. The differing projections from the perirhinal and parahippocampal areas suggest that the two streams of processing remain segregated until the 'what' and 'where' converge within the hippocampus (although some connections exist between the perirhinal and parahippocampal cortices and between entorhinal areas). Outputs of hippocampal processing involve feedback into the entorhinal, perirhinal and parahippocampal cortices and finally to the neocortical areas from which the inputs to the MTL originate (Eichenbaum et al., 2007).

To understand how much of a contribution the MTL makes to memory performance, several researchers have examined memory performance post extensive MTL damage. One of the earliest clinical neuropsychological investigations of this was by Milner (1962) who demonstrated that a hand-eye coordination skill of mirror drawing could be learned by severely amnesic patient H.M., over a period of time, without the recollection of having practised and learned the task. This was amongst the first studies to indicate that memory is not a unitary system. Following these findings, several other studies on amnesic patients have been conducted (see Brown and Aggleton, 2001 and Eichenbaum, Otto and Cohen, 1994 for reviews), however other alternative ways to investigate (somewhat) localised hippocampal damage have had more consistent results. For example, studies have investigated hippocampal damage following cerebral hypoxia, to which the hippocampus is particularly sensitive. Hypoxic damage results in neuronal loss largely confined to the hippocampus (Gadian, Aicardi, Watkins, Porter, Mishkin and Vargha-Khadem, 2000) and individuals who undergo damage to this area have been shown to exhibit disproportional deficits in relational compared with item recognition (see section 1.4.4 for an explanation), (Holdstock, Mayes, Gong, Robersts and Kapur, 2005). Several other studies have also confirmed that recollection is selectively impaired in hypoxic patients (e.g., Yonelinas, Otten, Shaw and Rugg, 2005) or see Aggleton, Vann, Denby, Dix, Mayes (2005) for similar results in patients with meningital hippocampal atrophy.

The lateral parietal and posterior cingulate cortices also have connections with the MTL structures (Kobayashi and Amaral, 2003). Event-related fMRI studies have investigated brain

activity during recognition to uncover whether parietal activity varies according to whether it is accompanied by recollection of contextual details or not. Recollection sensitive activation (for example, source recollection and study-depth status during retrieval) is observed in medial and lateral parietal regions (Henson, Rugg, Shallice, Josephs and Dolan, 1999; Dobbins, Rice, Wagner and Schacter, 2003; Eldridge, Knowlton, Furmanski, Bookheimer and Engel, 2000; Wheeler and Buckner, 2004; Henson, Maquet, Dolan and Rugg, 2002). More specifically, the identified regions include the inferior parietal cortex, notably the intra-parietal sulcus (IPS) and the inferior parietal lobule (IPL). Several studies have also consistently revealed activation in the posterior parietal cortex or PPC (Wagner, Shannon, Kahn and Buckner 2005) when items are familiar or 'known', even when in error (Wheeler and Buckner, 2003; Kahn, Davachi and Wagner, 2004). Activations in the PPC increase during Remember judgements and the recollection of spatial and temporal contextual event information (Henson et al., 1999; Dobbins et al., 2003; Eldridge et al., 2000; Wheeler and Buckner, 2004). Activity in the PPC is also measured during forced-choice tasks when retrieval is oriented towards episodic recollection rather than semantic knowing (Dobbins et al. 2003; Dobbins and Wagner, 2005). Furthermore, functionally distinct lateral parietal sub-regions are differentially sensitive to recollection success and perceived familiarity. In one such study, Wheeler and Buckner (2004) identified regions along the IPS that increase for remember and know judgements similarly compared to correct rejections and interpreted this finding to reflect an effect that tracked item familiarity. That study also revealed two left PPC regions, lateral and posterior to the IPS that show increased preferential response for remember judgements (also see Yonelinas et al., 2005; Henson et al., 1999 and Eldridge et al., 2000). Taken together these studies suggest that multiple distinct foci in the PPC are modulated by remember judgements. More specifically, these regions include medial posterior inferior parietal regions, including medial regions near the precuneus and the superior parietal cortex, which during tests are correlated to remember responses (Kahn et al., 2004; Henson et al, 1999; Dobbins et al., 2003 and Eldridge et al., 2000). Know responses in contrast appear to be correlated to responses in left IPS (Wagner, et al., 2005).

Additional strands of research include animal pathology studies, which have demonstrated connections between the MTL and prefrontal cortex. For example, in monkeys the IPL has direct and reciprocal projections to the parahippocampal cortex (Lavenex, Suzuki and Amaral, 2002) and direct projections to the hippocampus (Rockland and Van Hoesen, 1999) and furthermore these papers demonstrate that along the midline, afferent connections to the retrosplenial cortex are dominated by MTL projections (see Wagner et al, 2005). Kobayashi and Amaral (2003) argue that the anatomy of the retrosplenial cortex means it provides an interface between working memory (executive functions) enabled by the prefrontal cortex, and, declarative memory functions served by the MTL. Although these studies have considered the homologies between the anatomy of the macaque monkey and humans, and should be considered with

caution, the PPC should be considered as a major pathway through which the MTL influences cortical information processing.

Methodological limitations are associated with any particular approach to investigating the brain bases of memory. For example, in brain lesion studies it is often difficult to determine the precise location and extent of brain damage, or whether damage has occurred outside of the thought of and suggested region. In imaging studies it is difficult to test whether a given region is truly necessary for a particular process. Animal models often present difficulty with interpretation when psychological studies of humans are mapped onto tasks used for animal models. Given the limitations of each approach, convergence across multiple methods is called for. ERP data provide another approach to the study of the brain. ERPs are analysed using regions of interest (ROIs) that are selected based on the memory system that the ERP activity is correlated with. The activity measured at the scalp is interpreted in terms of its underlying cortical correlates. For the current set of studies, appropriate ROIs have been selected based on previous findings from fMRI, pathology and animal studies, which have informed the ERP analysis approach. ROIs have also been selected following previous ERP findings on memory (see the methods section for each experiment for more detail). The next section of this thesis reviews the evidence gathered from the methodological approach most relevant for the work carried out in the current thesis, which is ERP and the correlates of the episodic and semantic memory systems.

1.8 ERP correlates of Episodic and Semantic Memory in TD individuals

The Old-New ERP effect (Sanquist et al., 1980; Warren, 1980) has consistently demonstrated deflections for studied old words relative to new words at retrieval occurring at approximately 300 ms post stimulus lasting several hundred milliseconds (for reviews see Rugg & Curran, 2007; Rugg, 1995; Johnson, 1995). These deflections are more often positive for old words than for new words. The ERP effects can be recorded at widespread locations on the scalp and can be used to record the magnitude of the Old-New effect in the EEG. As recognition requires discrimination between old and new items, the differences between the two classes of stimuli are considered to reflect the retrieval and post retrieval cognitive processes the individual engages during recognition (Allan et al, 1998). Further, the recognition Old-New ERP potentially reflects the estimated neural activity during recognition in response to stimuli belonging to various conditions of an experiment, for example, old (Remembered/Known) versus new.

Converging evidence has suggested that Remembering and Knowing can be dissociated at a neural level. For example, ERP Old-New effects for Remembering and Knowing have been distinguished in terms of temporal and topographical scalp distributions. Remember responses have been associated with parietal Old-New effects (Voss & Paller 2008; Curran, 2000;

Friedman & Johnson 2000; Mecklinger 2000; Paller & Kutas 1992; for a review see Rugg & Curran, 2007). This is a positive going ERP with an onset of approximately 400-500 ms. The suggestion that the parietal Old-New effect indexes conscious Remembering is supported by evidence which has shown that correctly recognised old items show enhanced positivity compared to missed old items and unstudied items (Van Petten & Senkfor, 1996; Rugg, Mark, Walla, Schloerscheidt, Birch & Allan, 1998). In addition the effect has also been recorded in response to episodic 'Remember' responses (Wilding & Rugg, 1996; Düzel et al., 1997; Smith 1993), and it has been distinguished from other ERP effects such as those associated with confidence and stimulus probability (Curran, 2004; Herron, Henson & Rugg, 2004). The effect is also sensitive to experimental procedures that are used to operationally define Remembering (for example, deep levels of processing to enhance Remember responses, Yonelinas 2002; Rugg et al., 1998). Additionally the parietal Old-New effect has also been shown to be sensitive to whether items are associated with successful or unsuccessful source judgements (Wilding & Rugg, 1996; Senkfor & Van Petten, 1998), which is considered to tap episodic memory. In a study by Wilding and Rugg (1996), participants were asked to make Old/New judgements to words and for those judged Old, participants were asked to indicate if the word had been presented by a male or female speaker during the study phase. In their study, the parietal Old-New effect was of a greater magnitude for successful as compared to unsuccessful judgements about the voice of the speaker.

Old-New effects for items rated as 'Know' have been temporally and topographically dissociated from those associated with Remember judgments. The first account of this was by Düzel et al. (1997) using the Remember/Know paradigm (see Chapter 3 for a detailed explanation of the procedure). More recently, Know Old-New effects have been termed the mid-frontal Old-New effect (called the "FN400" by Curran, 2000 & Paller, Voss & Boehm, 2007) occurring at approximately 300-500 ms post stimulus (Rugg & Curran 2007; Curran, 2000; Mecklinger, 2000). The ERP has been identified alongside parietal Old-New effects in Remember/Know tasks. Research in support of the mid-frontal Old-New effect for Know responses is supported by experimental findings that show that manipulations that enhance Remember responses and not Know responses can also enhance parietal Old-New effects but not mid-frontal Old-New effects. Curran (2000) demonstrated this dissociation using inconsistent pluralities of words from encoding-to-test phases. In his study, lure items that were closely related (plurality reversals, for example 'cookies') to studied words ('cookie') were used to elicit high rates of false alarms by participants in a recognition test. The rationale behind the induction of a high rate of false alarms was that semantic memory and Knowing, would be driving this type of judgment since it is by definition void of the kind of detailed contextual information that would support accurate retrieval (or rejection) of plurality reversed lures. The results demonstrated that reliable parietal Old-New effects were only demonstrated by correctly recognised old items.

Conversely, the mid-frontal Old-New effect was recorded for both studied items and incorrectly endorsed (as old) plurality reversed items. Nessler, Mecklinger and Peney (2001) have demonstrated similar findings with ERPs for illusory memories, where both true and false (associatively related, but non-studied) recognitions revealed early mid-frontal Old-New effects from 300-500 ms, but later parietal Old-New effects from 500-700 ms were reduced for false recognition compared to true recognition. The findings suggest that brain activity for Remembering is reduced (i.e. less recollection) during false recognition compared to true recognition whereas activity associated with Knowing is equivalent. Taken as a whole, this body of evidence indicates that Know ERPs can be topographically and temporally dissociated from those associated with Remembering, and suggests that these judgments engage partially non-overlapping neural generators.

Additional evidence using picture stimuli (as opposed to words) and the Remember/Know procedure has also supported the argument for distinct ERP effects for Remembering and Knowing. Curran and Cleary (2003) presented old pictures and highly similar lures (mirror reversals to evoke increased Know experiences) to participants, and found ERPs consistent with the early mid-frontal Old-New ERP effect for Know judgements and later parietal Old-New effect for Remember judgements. In this study mid-frontal Old-New ERP effects were observed for incorrectly endorsed mirror reversed lure pictures relative to correctly rejected lure pictures (Know judgements), but not when recognition was associated with a Remember response (a correctly identified studied picture relative to correctly rejected lure picture). These findings are convergent with previous studies using word stimuli and furthermore provide evidence to confirm that these effects are not specific to well learned verbal stimuli such as words (see Yovel & Paller, 2004 for a similar study with novel face stimuli).

Although recognition-related mid-frontal and parietal Old-New effects associated with semantic and episodic memory are clearly distinct from one another, they co-occur with other ERP wave-forms that are not necessarily associated with memory retrieval processes (Olichney, Van Petten, Paller, Salmon, Iragui & Kutas, 2000; Spencer, Abad & Donchin, 2000). The N400 ERP component, for instance occurs in the same time-window as the mid-frontal Old-New effect associated with 'Knowing' and is typically observed in studies of language processing. The N400 is small when printed or spoken words are presented in a meaningful context (e.g., after a spoken word or a fragment of a sentence), but larger when printed or spoken words are presented out of context (Kutas & Van Petten, 1994). For TD individuals the language related N400 ERP component is attenuated for repeated words in unrelated lists, repeated sentences or when spoken words are repeated (Van Petten, Kutas, Kluender, Mitchiner & McIsaac, 1991; Besson, Kutas & Van Petten, 1992; Besson & Kutas, 1993). The deflections in the ERP occur at approximately 250 ms post stimulus and have been interpreted as a sign of facilitated semantic

processing of 'meaning' which occurs because of the previous presentation of the stimulus (Olichney et al., 2000). Although the temporal overlap between the N400 and the mid-frontal Old-New effect associated with Knowing may indicate similarities in underlying processes, the latter shows a differing topography from the N400, and is more frontal than central, indicating that these ERPs are not relying upon the same neural generators (see Rugg & Coles, 1995). It is nevertheless interesting to note that neural activity associated with the processing of 'meaning' should temporally coincide with the engagement of a memory system that is thought to be important for representing knowledge of 'timeless' facts, which would include the meaning of words.

Similar to how the N400 temporally coincides with the mid-frontal Old-New effect, another ERP component (the P300 or P3) coincides with the parietal Old-New effect associated with Remembering. The P300 is sensitive to factors such as the probability of occurrence of an eliciting stimulus and the confidence with which participants respond to stimuli (Polich & Kok, 1995). As Remember responses are associated with a higher level of confidence, it has been suggested that the parietal Old-New effect includes contributions from the neural generators of the P300 (Spencer et al., 2000). However, the parietal Old-New effect is unlikely to be reduced to just a modulation of the P300. Studies that have employed confidence judgements within their response criteria have been especially useful for this debate as effects of confidence and recollection have been shown to be topographically dissociable, with recollection demonstrating more pronounced left lateralised topography (Woodruff, Hayama & Rugg, 2006). It is also unlikely that the parietal Old-New effect reflects stimulus probability. Herron, Quayle and Rugg (2003) employed a manipulation in a recognition memory study to investigate the probability of an 'old' word occurring. The authors varied the proportions of old words relative to new words and found that regardless of stimulus probability, the Old-New effect at left parietal electrode sites remained constant, providing strong evidence to suggest that the parietal Old-New effect is largely and most predominantly associated with recollection (Woodruff et al., 2006).

Some studies have also observed late-onsetting frontal positivity for Remembered old items. This ERP effect was first observed by Wilding and Rugg (1996) termed the 'right frontal Old-New effect'. More recently this modulation has been termed the 'Late Frontal Effect' or LFE (Wolk, Sen, Chong, Riis, McGinnis et al., 2009) as the effect has been shown to occur over both left and right frontal sites (but more often maximal at right hemisphere sites). This effect can begin as early as 600 ms post stimulus and has been shown to persist for over 1s. A number of studies have noted the effect, often attributing it to control-related functions, for example, post-retrieval monitoring (Allan, Dolan, Fletcher & Rugg, 2000; Curran, Schacter, Johnson & Spinks, 2001; Ranganath & Paller 2000). Rugg et al., (2002) proposed that the LFE occurs whenever a retrieval attempt is ambiguous, or requires evaluation, such as in source memory tasks.

Supporting this argument, several other researchers have suggested the effect may index retrieval effort when representations are impoverished (Ally, Waring, Beth, McKeever, Milberg & Budson, 2008; Rugg & Allan, 2000), for example, when a studied item can be correctly identified as 'old' but identification of the source of the information cannot be recalled.
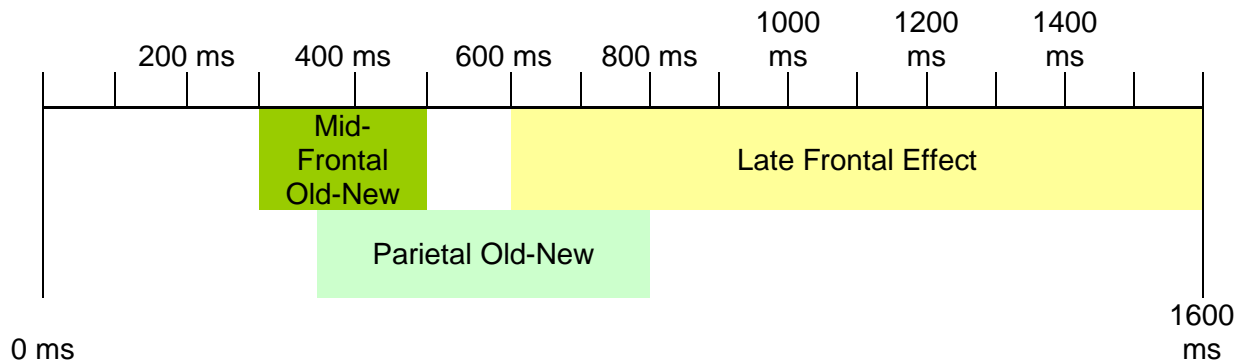
Figure 1.1: Summary of memory-associated Old-New effects reported in TD literature (Rugg & Curran, 2007; Wolk et al., 2009).

In conclusion, a large body of research on TD individuals has emerged to suggest that Remember and Know judgements demonstrate temporally and topographically dissociable ERP Old-New effects (see Figure 1.1), and that these judgements have qualitatively different characteristics during retrieval. Furthermore the distinct topographical patterning of the effects suggests that these processes are associated with activity in distinct neural generators. The precise temporal patterning and the topography of these effects provide a potentially useful tool for the investigation of the neural processes underlying memory in populations with atypical memory function, such as people with ASD.

Chapter 2 : ELECTROENCEPHALOGRAPHY AND EVENT-RELATED POTENTIALS

As described in section 1.8, the EEG can be time-locked to the presentation of a stimulus and averaged over a large number of trials. Over repeated presentations of certain types of stimuli, the EEG yields an ERP that can be characterised statistically in terms of its time course and topography (distribution of electrical activity across scalp electrodes) to inform specific research questions. ERPs have a high temporal resolution and are particularly suited to assessing cognitive functioning as they allow neuropsychological activity to be assessed with millisecond precision. The next chapter of this thesis will review the experimental procedures that have been used to identify the ERP findings discussed in section 1.8. These experimental procedures form an important basis for the research conducted in the present thesis.

As we have already seen, many studies have demonstrated changes in the patterning of ERPs in response to experimental manipulations of material in memory tasks. For example, in word recognition memory tests, studies have consistently demonstrated differences in the ERP depending on a word's study status. That is, words correctly recognised as having been studied ('Old') give rise to different ERPs than those that are correctly recognised as unstudied ('New'). In the case of the Remember/Know paradigm, ERPs can further be classified in terms of whether words are correctly identified as Old and Remembered or Old and Known, which can be contrasted directly or separately with the ERPs elicited by correctly identified New words. ERPs and their topography can be used to address questions the cognitive processes thought to underlie certain behaviour. For instance, conclusions can be drawn from differing topographies since such differences imply that the conditions of the experiment engaged non-overlapping neural generators and therefore non-overlapping cognitive processes (see Rugg & Coles, 1995 for a rationale). Although in the context of memory tasks, ERPs can be recorded during the encoding as well as the retrieval of stimuli (see Yovel & Paller, 2004; Duarte, Ranganath, Winward, Hayward & Knight, 2004 for examples or Yonelinas, 2002 for a review), the majority of ERP research investigating Remember/Know judgements in TD individuals has focussed on retrieval (see Rugg & Curran 2007 for a review), and therefore this will be the focus for the thesis.

2.1 The Neural Origin of ERPs

As described in section 1.5, the EEG is a recording of electrical potentials that are created by current flows originating from neuronal populations. EEG activity arises from two types of neuronal electrical activity. The first results from the axons of neurons which propagate action potentials from the cell body to the terminal buttons of synapses. The second is created by

postsynaptic potentials (PSP), which are changes in the membrane potential in the post synaptic terminal of a synapse. When an action potential reaches the pre-synaptic axon end, neurotransmitters are released into the synaptic cleft and bind to the receptor of the postsynaptic neuron where they can trigger the opening or closing of ion channels. This then leads to a change in the membrane potential of the postsynaptic neuron. As the EEG is recorded from the surface of the scalp it mostly reflects postsynaptic potentials at cell bodies and dendrites of the neurons, which summate and are thus easier to detect from a distance (Rugg and Coles, 1995). EEG is typically measured from between 16 and 256 electrodes that are placed in a standardised arrangement on the scalp surface (international 10-20 system, Jasper, 1958). The greater the number of electrodes used, the greater the spatial resolution of the EEG.

ERPs use time-locking methods which increase the signal to noise ratio by cancelling out artifactual (non-brain related EEG) activity against the stimulus-related activity. Eye movements, eye blinks, cardiac signals, muscle noise and line noise contaminate the EEG with artifacts that need to be omitted from the computation of the ERP. However, omission tends to diminish the signal-to-noise ratio because of a loss of observations. To combat this reduction in signal quality, experiments are designed to comprise a large number of trials, which allows for a proportion to be rejected whilst still retaining a good signal to noise ratio. Eye blink artifacts, which show characteristic waveforms in the EEG trace can be rejected by inspection although the majority of researchers use automatic corrections that can be applied to the data to remove eye-blink artifacts using arithmetic algorithms (Gratton, Coles & Donchin, 1983; Luck, 2005).

2.2 Interpretation of ERPs: Measuring Latency and Amplitude

ERP traces can inform cognitive research in many ways. Comparisons begin by plotting the ERP waveforms obtained from two experimental conditions (time on the x axis and amplitude on the y axis, see Figure 2.1).
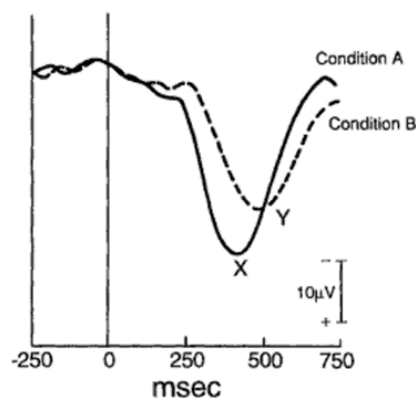
Figure 2.1: Hypothetical average ERP waveform obtained from a recognition memory task with two conditions, A and B. Condition A presents the ERP average waveform for correctly recognised studied Old stimuli and condition B presents the ERP average waveform for correctly rejected New stimuli (reproduced from Rugg & Coles, 1995, p. 30).

The series of peaks and troughs observable in the ERP waveform reflect the sum of relatively independent components. As an example relevant to the work in this thesis, assume that the experimental task associated with the ERPs in Figure 2.1 was a recognition memory task and that condition A represents the average ERP for studied Old stimuli, and condition B represents the average for New stimuli. Where differences in the ERP are observed, these can be analysed statistically to determine whether the waveforms in the two conditions differ reliably or merely by chance. It should be noted that, as in all instances of null observations, occasions of no significant difference in ERP traces between two conditions, does not justified the conclusion that the experimental manipulation did not give rise to differential brain activity (Rugg and Coles, 1995). It may simply be that the differential activity was too small to summate and generate a large enough post synaptic potential to be measured at the scalp.

In the illustration above, there are a number of differences between the waveforms that are important to note. First the ERPs diverge and the time at which this divergence first occurs can be considered an upper boundary of time at which the brain activity associated with the two experimental conditions differs. The time is considered an 'upper limit', because it is possible that processes differed before this time, but were immeasurable. Interpretations of the time at which ERPs diverge are often aided by the conceptualisation of the experimental paradigm. For example, in the case of recognition memory it is possible to estimate the upper bound time the participant needed to discriminate the Old word from the New word by measuring the point at which the 'Old' and 'New' ERPs begin to diverge (Rugg & Doyle, 1992). A second feature worth noting about ERP differences concerns spatial and topographical dimensions. For example, if one condition of an experimental manipulation revealed a characteristic waveform with a particular topography (e.g., a parietal peak) and another condition revealed a waveform at a different location (e.g. a frontal peak) it would suggest that the experimental manipulations engaged at least partially differential neural generators. In turn, this would support notions of differences between the cognitive processes underlying the two conditions. Finally, ERP waveforms can be compared in terms of their peaks (points marked X and Y on the illustration), both in terms of the amplitude of peaks, and in terms of the time at which the waveform reaches a maximum positive or negative value. If peak amplitudes differ it can be inferred that one experimental condition engages a certain process more or less than another condition whereas differences in peak latency can indicate that whatever process the waveform measures happens faster in one experimental condition than in the other.

In addition to comparing two (or more) ERP waveforms, it is also possible to calculate difference waveforms that directly represent, as the name implies, the difference in ERPs between conditions. In the case of recognition memory paradigms, for example, Old-New difference amplitudes can be calculated by subtracting ERP amplitudes associated with 'New'

stimuli from those associated with 'Old' stimuli within a given time window. For word recognition, Old-New effects typically occur between 300-800 ms (Rugg & Curran, 2007) and are hypothesised to result from cognitive processes that an individual engages during recognition. The earliest accounts of this phenomenon were by Sanquist, Rohrbaugh, Syndulko and Linsdley (1980), and Warren (1980) and have been widely replicated in the literature. The advantage of calculating ERP Old-New effects is that these difference waves facilitate the analysis in experiments employing the Remember/Know recognition procedure where they can be used to inform specific research questions about episodic and semantic contributions to recognition memory.

The EEG/ERP methodology has been especially useful in research for investigating covert memory processes, as it allows the ascertainment of putative underlying processes without having to rely on participant behavioural responses. In this way, ERP studies can covertly monitor the processing of information by the participant whilst they engage in the task, and not rely on a response made at the end of the test, as is the case for behavioural testing. In comparison to other physiologically-based measures such as fMRI, EEG has the advantage that it offers excellent temporal resolution (millisecond precision under optimal conditions). FMRI and other hemodynamic methods offer resolution in the order of seconds (because of the slow nature of the hemodynamic response). One disadvantage of EEG is that it has a limited spatial resolution, although this can be improved by using high density electrode caps (for example, caps with 256 electrodes, see section 2.4). The conclusions that are drawn from EEG research should focus on the strengths of this methodology (its temporal resolution) and rely on converging evidence from fMRI to draw any conclusions about the neural generators of brain activity underlying a particular cognitive process.

2.3 Latency versus Amplitude

Averaged ERP waveforms are often based on a larger number of trials in some conditions than in others. For example, in the present research, waveforms from the ASD and TD groups may have different noise levels because one group may be more prone to artifacts (e.g., movement artifacts, ocular artifacts) than the other group. Assuming all else to be equal, waveforms created by averaging a larger number of trials will contain less noise than waveforms created by averaging fewer trials. Consequently, a comparison between waveforms from the different participant groups will be a comparison between waveforms with different amounts of noise, even though the number of trials may not reliably differ between groups. The question is whether these differences in noise level are a problem.

Luck (2010) argues that differences in noise level can present a problem or not depending on what you choose to measure (peak amplitude or mean voltage amplitude). In other

words (depending on the measure) differences in noise level between groups may or may not bias the results of a study (or constantly shift the direction of the average mean voltage amplitude, either positively or negatively). Peak amplitude measures are a biased measure that will tend to give larger values in conditions with greater noise as smaller numbers of trials contribute to the averaged waveforms (Luck, 2010). Peak amplitude measures will be larger for conditions with noisier waveforms as the peak measure finds the most extreme value present in the ERP waveform (see Figure 2.2). When the waveform is noisier, the most extreme positive value will tend to be more positive, just as the most extreme negative value will tend to be more negative, which often results in peak voltage amplitude being a biased measure. Mean voltage amplitude, on the other hand is a more unbiased measure that can be used even when noise levels differ across conditions. Theoretically, the average value over an infinite number of experiments would be equal to its true value.
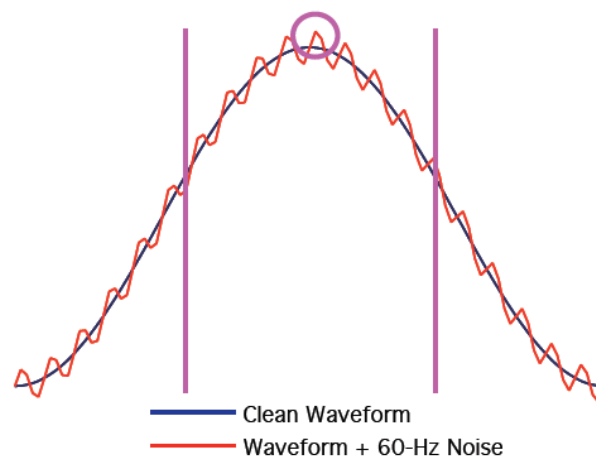
Figure 2.2 Example of a clean waveform and a waveform with 50 hz noise added (taken from Luck, 2010, p. V2).

The use of mean or peak voltage amplitude measures over the specified measurement window may result in different findings. The positive and negative bumps caused by the 60 hz noise in the example above (Figure 2.2) will cancel each other out and the mean voltage amplitudes over the noisy and clean data will be close. They will not be exactly the same, but using this measure, the mean amplitude for the noisy data may sometimes be larger or smaller than the clean data. However the important thing to note is that the mean voltage amplitude measure is not biased in either direction by the noise. With noisy data, using mean voltage amplitude measures is therefore a less biased measure of the waveform compared to peak amplitude measures. This may increase our chance of a Type II error (rather than Type I error which may increase with peak voltage amplitudes).

For the research presented in the current thesis, it was expected that the ASD group

would have averaged waveforms that contained more noise than the TD group. The main contributor was expected to be movement artifact (from mannerisms) and a consequential loss of trials. A conclusion based on a comparison of peak amplitude between groups risked bias (more extreme measurements being recorded in the ASD group). In experimental designs with larger stimuli sets this analysis may pose less of a problem, however for the study designs used in the present studies (recognition memory paradigms with <400 matched word/picture stimuli) this type of analysis is more questionable than mean voltage amplitude analyses. Additionally, the analyses presented here aimed to replicate current findings in TD individuals and remain consistent with the majority of research to date using recognition memory paradigms (see Rugg and Curran, 2007 for a review). Mean voltage amplitudes for recognition judgements of interest were analysed in their expected time windows based on prior knowledge (see section 1.6 for the specific latencies of interest).

2.4 Interpretation of Sensor Level Measures

As mentioned at the start of Chapter 2, the EEG technique (as with all other techniques) has some strengths and weaknesses. The main strength of the method is that it affords millisecond temporal resolution as well as an 'online' observation of neural activity during behavioural tasks. Its main weakness is its limited spatial resolution. The analysis of ERP topography from sensors at the scalp can be used to make statements about the underlying cortical source of neural activity (for example, the maximum voltage was measured over parietal cortex). However, sophisticated measures such as source localisation techniques (using mathematical modelling) are available and can be used to identify the loci of neural activity that gives rise to these voltage distributions.

The source localisation procedure works by calculating the scalp potentials that would result from a hypothetical dipole (a pattern of current distribution). Along with recorded EEG data, this is used to estimate the source of the current. Although the method uses sophisticated analysis techniques to determine the source configuration from the scalp topography, there are difficulties associated with the process of determining it. This is because, given a large number of dipoles distributed through the brain the number of possible combinations of those dipoles that can result in a particular distribution is numerous (i.e., a given scalp topography has an infinite number of source configurations, Helmholz, 1853). This is true even though a specific cortical source produces unique scalp topography. Powerful models of source localisation attempt to combat the challenges associated with this methodology by making some assumptions. For example, they assume models of the head that take into account the fact that the voltage measured at the scalp reflects a field potential that has travelled through a three-dimensional space, with the conductive properties of the brain, dura and skull each varying and having

significant impact on what neural activity can be measured. The analyses do this by modelling the head as a sphere in order to derive the mathematical expressions used for source localisation. The modelling technique also assumes the head has a homogenous conductance with the surface of the sphere representing the heads surface. Second, the localisation technique also takes into consideration that only certain configurations of neurons can lead to potentials that are measurable at the scalp surface (the dendrites of the pyramidal neurons are primarily responsible for generating the EEG signal). Hence, the methods model the cortex as a dipole sheet (positive and negative layers of charges, Nunez, 1981).

Source localisation provides a means of gaining knowledge about brain functioning and can estimate location, orientation and strength of neural electrical sources of brain activity. However, given that the source localisation technique makes assumptions about the shape of head and the way cortical activity is modelled (see above), its accuracy is brought into question. As discussed in the previous sections, there are more robust methods that can be used to identify the origins of neural activity (fMRI) that would provide a more firm basis for any conclusions about cortical correlates that can be drawn from these studies. The conclusions of the analyses presented for the current research are guided by the strengths of the EEG methodology, (the temporal resolution). Where topographical patterns are interpreted, these are in terms of maxima and minima voltage amplitudes measured at the scalp surface and are taken to suggest that the conditions of the experiment engaged non-overlapping neural generators and non-overlapping cognitive processes (see Rugg & Coles, 1995, and Chapter 2).

2.5 The use of Region of Interest Analyses

2.5.1 Electrode Factors

The grouping of electrodes into Regions of Interest (ROIs) requires careful consideration in experimental designs such as those used for the current research. For example, if the ERP measured from the left hemisphere electrodes is predicted to be systematically different from right hemisphere then a factor of 'laterality' should be entered into the ANOVA. This is also the case for anterior versus posterior electrode sites. Advantages of grouping electrodes into ROIs include reducing the error variance in the ANOVA and reducing Type I error created as a result of multiple comparisons (e.g., multiple *t* tests). ROI analysis can also add information about the laterality of the effects of interest.

The levels on each factor entered into the ANOVA must be comparable to be meaningful. As a result of this, one caveat with the ROI approach arises when considering electrodes that lie

at midline scalp sites (only one electrode lies on the midline which means fewer electrodes are averaged into the region). Problems for ROI analyses can also occur on a low electrode density cap or, where multiple electrodes are eliminated from the analysis (due to movement/blink artifacts). Electrodes without corresponding levels for each of the factors (for example, a good signal at P3 but not at P4) cannot be entered into the ANOVA and must be dropped from the analysis. This is because each ROI (or additional factor) needs to represent a 'real' source of variance; if not the effects of other important factors may be undermined in the analysis. Each additional factor adds a cost to the degrees of freedom and therefore increases the *F*-value required for statistical significance. If the cost of increased degrees of freedom is not met and offset by increased accuracy, then the additional factor will be detrimental to the power of the test. Therefore additional and unnecessary factors should be avoided. Only if past evidence or theory-driven rationale is present should additional factors be added to the analysis, providing the data are of good quality. These principles will be applied to the current analyses.

2.6 Derivation and Interpretation of Topographical Maps

ERP voltages are recorded over time (ms) and space (distribution on the scalp) which results in two ways to display ERP data. One is to present the ERP waveforms, that is, voltage by time (the waveform itself). The second is to present the change in voltage over space, or the scalp distribution/topography map. Both the ERP waveforms and topographic maps can represent time and space (waveforms from multiple electrodes or topographic maps from multiple time windows), and best practice includes the presentation of both types of display.

2.6.1 How are difference waveforms topographical maps created?

To examine the differences in physiology for correctly recognised words versus correctly rejected words, the waveform for correctly rejected New words will be subtracted from the waveform for correctly recognised/Remembered/Known Old words. The resultant ERP 'difference' waveform can be presented in topographical map form, and is assumed to represent physiological processes that are different between the two conditions, for example, physiological processes that are specific to overall recognition. More specifically these ERP difference waveforms can be looked at separately in terms of Remember and Know responses. This subtraction has been used commonly in Recognition and Remember/Know memory paradigms (for a review see Rugg and Curran, 2007).

2.6.2 Interpretation

Topographical maps provide a useful and simple way to examine ERP differences in set time windows; however there are a number of points to consider when using this approach. First, the subtraction methods from which the difference wave and topography map are calculated

differentially affect the ERP recordings from which it is derived. For example, the choice to subtract waveform '1' from waveform '2' or vice versa will have consequences for the polarity of the resultant difference waveform. Often (and particularly salient in memory research with ERPs), particular methods of subtraction are commonly used where waveforms for 'New' stimuli are subtracted from recognised 'Old' stimuli (which consequently results in a positive-going difference waveform).

2.6.3 Validity of topographical maps

Changes in the ERP waveform can be presented as a topographical map across the scalp and can provide a visual presentation of the topography underlying a component. The maps are particularly useful for comparing experimental conditions across subjects, however usually the maps alone are not adequate, for example, when determining the fine structure of a waveform at a given point in time (usually topographical maps average over a time window resulting in a reduction in resolution).

One protocol to examine the differences between two conditions in psychophysiological experiments is to subtract the recorded waveform in one condition (waveform 1) from the waveform recorded in a different condition (waveform 2). This yields a 'difference' waveform and is assumed to represent the physiological processes that are different between the conditions. Indeed, given the design of most ERP experiments, the subtraction method offers a simple way to examine ERP differences between 2 conditions of interest. This said it is important to bear in mind that the subtraction method may affect the two recordings from which the difference waveform is calculated in different ways. For example, if the participant changes the way they process information between the two recordings, or if the latency of the ERP effect(s) shifts. These issues are more relevant where novel subtractions are being carried out. The current research uses a subtraction method that has been commonly used in recognition memory paradigms in TD individuals (Rugg and Curran, 2007) and will form the basis of all comparisons for the ASD group.

Although the difference waveform offers a convenient visualisation of the ERP data, on their own they present a condensed form of the original data (a processing step, i.e., a subtraction, has already been carried out). The difference wave does not show which conditions of the experiment (if any) contained any additional ERP components, or, which of the deflections in the difference waveform were specific to a component in waveform 1, and which were specific to a component in waveform 2. Additionally, the difference waveform does not allow the reader to visualise how much noise there was in each of the conditions of interest (for example, if there were fewer trials and more noise in the condition that waveform 1 was derived compared to the condition of waveform 2). A topography map plots the difference wave onto a 2D map of the

scalp, and so the limitations of difference waves project onto the validity of topographical maps.

As topographical maps present the *difference* in neural activity between two conditions, alone they do not give the reader a sense of the noise levels in each of the conditions. Additionally they do not provide enough information about the origin of the deflections in the difference wave. There is also a significant loss in the temporal information available in a topography map. 2D topographical maps cannot adequately determine the component structure as usually they are presented over averaged time-window segments. Due to these limitations, it is essential to present the difference wave /topographical 2D map alongside its original ERP waveforms; usually these are overlaid on a time (ms) by amplitude (mV) plot.

For the current research, to avoid invalid interpretations from the presentation of *solely* topographical difference maps, these maps will be considered alongside the original waveforms from which they were derived. The topographical difference maps will provide a quick and ready visual representation of the data gathered from the different conditions (Remember/Know), time windows and groups (ASD/TD) in these studies. For all experiments, correctly rejected New stimuli will be subtracted from correctly recognised Old stimuli, allowing a clear delineation of polarity of the difference waveform. A positive difference waveform will be recorded where the ERP for Old stimuli was more positive than the ERP for New stimuli, and a negative difference waveform will be recorded where the ERP for Old stimuli was more negative than the ERP for New stimuli. This will be consistent across studies to aid the comparison of findings.

The research presented in this thesis is the first of its kind to be conducted with individuals with ASD. For each study, we aimed to replicate current findings in TD individuals and observe the pattern of findings in the ASD group. Consequently, the analyses that have been conducted with the present data (in terms of time windows chosen) will be guided by previous findings and analyses in TD individuals. This was done in order to remain consistent with existing literature in our TD group.

Chapter 3 : AIMS, BEHAVIOURAL PARADIGMS AND METHODOLOGY

3.1 Aims of the Thesis

The literature review in Chapter 1 demonstrates that the autism spectrum comprises a range of deficits in the domains of imagination and social interaction. These deficits have dominated the field of psychological research in ASD over the past two decades but recently increasing research has been done on the non-social aspects of the spectrum, such as executive functioning, perceptual processing, styles of cognitive processing and memory. The present thesis aims to build upon the existing behavioural research on memory in ASD by linking recently established patterns of strengths and weaknesses in memory with electrophysiological activity in different cortical regions of the brain. Knowledge gained from linking these, will refine models of memory in ASD and elucidate similarities and differences between memory in ASD and that of TD individuals. The next section provides a summary of the aims and studies carried out in the thesis.

Experiment 1: The literature review in Chapter 1 demonstrates that ASD individuals show a characteristic pattern of memory performance, where immediate memory, cued recall and recognition are preserved, but performance on measures of free recall is reduced particularly when multi-trial procedures are used or when the to-be-remembered information can be organised conceptually (see Boucher & Mayes, *in press*). Therefore, the main focus of this thesis was to determine whether areas of preserved memory in ASD, such as recognition memory, are supported by the same neural processes as in TD individuals. TD individuals demonstrate Old-New recognition ERP effects, which are positive deflections in the ERPs for studied words relative to new words (Rugg & Curran, 2007). The first study of this thesis aimed to verify whether the Old-New effect occurs in ASD using a standard Old/New recognition memory test.

Experiment 2: According to Tulving (2002), recognition memory is characterised by contributions from autonoetic and noetic conscious awareness, each of which reflect the operation of different memory systems; the episodic and semantic memory system respectively. These states of conscious awareness can, and have been measured in individuals with ASD by asking whether correctly recognised items in a recognition memory test are 'Remembered' (involving a re-living of the spatial and temporal context of the study episode) or 'Known' (judgements void of this mental re-living of the study episode). In experiments using the Remember/Know paradigm (Bowler et al. 2000a, b, 2007), ASD individuals demonstrate significantly less Remembering and more Knowing compared to matched TD individuals. These results are observed in the presence of intact overall recognition memory and have been

interpreted as a specific impairment in episodic memory and autonoetic conscious awareness in ASD. Experiment two of the thesis aimed to replicate this finding at the behavioural level in order to provide a solid foundation for study three, which aimed to investigate these memory phenomena using ERPs.

Experiment 3: Experiment three was designed to build upon the first two studies by measuring the ERP correlates of Remembering and Knowing in an illusory memory task with ASD and TD participants. For TD individuals behavioural Remember/Know judgements have been linked to electrophysiological measures at different scalp topographies and time windows. Studies have identified an early mid-frontal Old-New effect maximal from 300-500 ms for Know judgments and a later parietal Old-New effect maximal from 400-800 ms for Remember judgements (see Rugg & Curran, 2007 for a review). The study aimed to elucidate if Remember and Know judgements in the ASD group were qualitatively similar yet quantitatively diminished, or, qualitatively distinct from those responses given by TD individuals.

Experiment 4: The previous studies revealed diminished Old-New effects in the ASD group; however they all used words as stimuli. Since ASD is characterised by atypicalities in the domain of language, it is possible that groups used different verbal processes during the previous experiments. This leaves open the possibility that the diminished Old-New effects observed for the ASD group were a result of atypical language rather than memory processes. To test this hypothesis, Experiment 4 used the same experimental procedure as study three, but presented participants with kaleidoscope images that were non-nameable and could not be assigned verbal labels.

Experiment 5: The episodic and semantic memory systems were measured in Experiments 1 to 4 using the Remember/Know paradigm; however the last study provided a convergence approach using the Inclusion/Exclusion paradigm. Experiment 5 required more stringent estimates of recollection by defining Remember judgements in terms of the successful recollection of the colour in which items were studied. The last study of the thesis was particularly important for the conclusions and discussion sections, as it was important the findings were not based on the assumptions of a single (Remember/Know) test procedure.

3.2 Recognition Memory Paradigms for the Current Thesis

The research discussed in Chapter 1 discussed the episodic and semantic memory systems in terms of the findings gathered from TD individuals using various types of experimental paradigms. The next section of the thesis describes the procedures and paradigms relevant for the current research and their theoretical background (also see section 1.3).

3.2.1 Remember/Know paradigm

The Remember/Know paradigm (Tulving, 1985b) was developed to measure the contribution of the episodic and semantic memory systems to recognition. The task involves presenting participants with a list of stimuli which they are asked to memorise, after which they are given a recognition memory test. Participants are asked to introspect on the phenomenology of their memories for the recognised stimuli, and specify whether they 'Remember' or 'Know' that a stimulus had appeared. 'Remembering' implies that participants are able to Remember something specific about the time the stimulus was presented such as what they thought about, or where precisely in a list a certain stimulus occured. Thus, Remembering involves the conscious recollection of the Self in subjective time. 'Knowing' that a stimulus appeared implies an absence of such autonoetic recollection[2], and a more 'selfless' knowledge that the stimulus has been previously encountered. For example, semantic Know responses characterise our knowledge for timeless facts, e.g., the boiling point of water, what the capital city of France is, what your mother's name is, etcetera. According to Tulving, 'Remembered' stimuli require richer episodic retrieval of information than those that are 'Known', and therefore distinguish between episodic and semantic memory. Tulving also acknowledges two differing states of conscious awareness to support episodic and semantic memory, and has named these 'autonoetic' and 'noetic' respectively (see section 1.3.3).

Uniquely, the Remember/Know paradigm measures episodic and semantic memory on

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[2] Memory process theorist's (see section 1.3.1), often use 'Recollection' and 'Familiarity' instead of 'Remember' and 'Know'. However, estimations of 'Familiarity' on the basis of 'Know' judgements, using the Remember/Know paradigm are not entirely justified. This is because 'Know' judgements do not provide an unbiased measure of 'Familiarity' (see Gardiner & Richardson-Klavehn, 2000). Remember/Know task instructions are for participants to make a Know judgement when they are sure the item has been presented, but it is not remembered, and not whenever the stimulus is familiar. Therefore, these instructions restrict the occurrence of Know judgements by specifying relatively stringent criteria, and so, underestimate the probability that an item is judged as familiar.

the basis of subjective self reports, meaning that reports of Remembering are not limited to some specific recall measure (such as the colour of the presented study stimulus, or which voice a spoken study stimulus was presented – as in the Inclusion/Exclusion paradigm, explained below). "Remember" judgements can include very idiosyncratic and personally relevant information from the study episode (e.g., "I Remember that because I had a twitch when it was presented").

3.2.2 Inclusion/Exclusion paradigm

In this paradigm, episodic memory is indexed by the ability to Remember something about the modality in which the item was studied. If participants episodically recollect the item, they should be able to say something about the time it was presented, whilst for judgements based on semantic memory, they should not. Participants are asked to study a list of stimuli (for example, some presented in blue versus some red) and are then asked to make, (1) old/new responses (*inclusion task)* and (2) blue/not blue responses *(exclusion task)* at test. The inclusion task, involves the inclusion of all studied items regardless of the colour in which they were presented, whereas exclusion involves rejecting two classes of stimuli; those that were studied but not blue (referred to as non-target old) and new items. Therefore during the exclusion task, the participant makes a selective response to one class of stimuli (blue images/targets) whilst the two other classes of stimuli receive the same response (non-targets/new). In order for performance on the exclusion task to be above chance, target and non-target stimuli need to be distinguished (an old/new discrimination will not suffice as both target and non-target stimuli are 'old'). As a response based on semantic memory alone will not yield accurate performance, the exclusion task is assumed to be based on the retrieval of contextual information from episodic memory.

The Inclusion/Exclusion task uses a strict measure of episodic memory by defining the aspect of the study environment that participants need to remember (e.g. the colour of items). It is possible that participants may Remember another aspect of the study environment (something more personally relevant), such as something that they thought of at the time when the stimulus was presented. However, if this information does not support the required discrimination of the Inclusion/Exclusion task, it will not count towards a target judgement, therefore reducing behavioural estimates of episodic memory (Yonelinas & Jacoby, 1996b). The procedure also assumes episodic memory is driving both target and non-target judgements during the exclusion task, however Herron and Rugg (2003) have provided evidence to suggest that non-targets can be excluded without episodic Remembering, but rather on the basis of a failure to elicit information regarding its source. In light of this argument, for the purposes of the research carried out in this thesis, the most conservative estimates (the successful recognition of targets)

will be analysed independently from less conservative estimates of episodic memory (non-target judgements) when deriving electrophysiological brain correlates of episodic memory, in order to make comparisons between groups.

Two methods; the Remember/Know paradigm and the Inclusion/Exclusion paradigm have been selected to examine the contributions made by episodic and semantic memory systems thought to underlie the operation of recognition memory. Both of these methods involve deriving estimates of recognition, which can be accompanied by the retrieval of contextual information or in its absence. A convergence approach has been used in order to avoid relying on one experimental paradigm and to avoid basing conclusions upon the assumptions of one particular test procedure.

3.3 Participant Selection

3.3.1 Diagnostic Instruments for ASD

ASD is diagnosed with respect to specific observable behaviours in both children and adults and several diagnostic instruments have been developed to assess the presence of the disorder (see Volkmar et al, 2005). The two most widely used instruments that have been developed for research purposes are the Autism Diagnostic Observation Schedule – Generic (ADOS-G), (Lord, Rutter, DiLavore & Risi, 1999), and the Autism Diagnostic Interview (ADI-R), (LeCouteur, Rutter, Lord, Rios, Robertson et al., 1989; Lord, 1997 ; Lord, Rutter & LeCouteur, 1994 ; Rutter, Bailey & Lord, 2003).

3.3.2 Autism Diagnostic Observation Schedule (ADOS – G)

The ADOS-G is a standardised, semi-structured assessment of the three areas described in Wing and Gould's account of the triad of impairments (1979), the DSM-IV (American Psychiatric Association, 2000) and in the ICD-10 (World Health Organisation, 1993). The assessment allows the administrator to observe behaviours that are important for a diagnosis of ASD such as the quality of communicative behaviours (eye-gaze, use of gesture), presence of stereotyped behaviours and unusual persistence on particular topics of discussion. The ADOS-G consists of four modules, each designed to test individuals of a particular age or developmental level and consisting of a schedule of activities which is administered in a one-on-one interview with the participant. A series of planned social presses are used to provide standard contexts in which a particular social behaviour is likely to appear for observation (e.g., asking about current or past relationships/work). Behaviours are scored and entered into an algorithm to aid the administrator in the formulation of a diagnosis. The algorithm specifies a minimum score to yield

a diagnosis of ASD as described in the DSM-IV or ICD-10.

The ADOS-G is useful for confirming clinical diagnoses of ASD from a wide range of ages and developmental levels. The ADOS-G is considered the 'gold-standard' measure for confirming clinical diagnoses of ASD for research purposes (Lord et al., 1999). All participants who took part in the research presented in this thesis reached the threshold for a diagnosis of ASD on the ADOS-G.

3.3.3 Autism Diagnostic Interview - Revised (ADI-R)

The ADI-R is a standardised semi-structured clinical interview with the caregiver of the child (aged two years and above) or adult with ASD. The ADI-R contains 93 items, which focus on language and communication, reciprocal social interactions, and restricted, repetitive and stereotypes behaviours (the three domains of the triad). The interview includes questions about current behaviour and about time periods in which certain behaviours were most prevalent (e.g., group play). Items focus on topics of early development, verbal and non-verbal communication, social development and play, interests, general behaviour, memory, motor skills, over activity and fainting. The content areas are scored by the administrator and entered into an algorithm. The algorithm specifies a minimum score to yield a diagnosis of ASD as described in the DSM-IV or ICD-10.

The ADOS-G and the ADI-R provide measures for identifying the presence of ASD (suitable for research purposes), and allow researchers and clinicians to reliably coordinate findings across multiple studies. The measures allow the combination of samples of individuals with ASD, collected from different researchers in different laboratories (Tager-Flusberg, Joseph & Folstein, 2001).

3.3.4 Autism Spectrum Quotient (AQ)

There are numerous other diagnostic measures that are shorter to administer (see Volkmar et al., 2005) and can provide a screening tool for ASD. The Autism-Spectrum Quotient (or AQ, Baron-Cohen, Wheelwright, Skinner, Martin & Clubley, 2001) was administered to all participants to (1) confirm diagnosis in the ASD group and (2) to screen the TD group for possible ASD-like behaviours (which would qualify them for exclusion from the study).

The AQ is a 50 item self-report questionnaire that measures levels of autistic traits in adults of normal intelligence in a forced-choice format. Each question allows the individual to indicate if they definitely or slightly, agree or disagree with the statement where approximately half the questions are worded to elicit an 'agree' response, and half 'disagree'. It includes questions about behaviours from five different areas, including: attention switching, attention to

detail, communication, imagination and social skills. Questions on the AQ were developed to reflect the domains of the triad of autistic symptoms (Wing & Gould, 1979; APA, 1994). Each question that is answered in a manner consistent with autistic traits (whether slightly or definitely) receives one point (maximum = 50 points). Adults with AS/HFA score significantly higher on the AQ than matched controls, where approximately 80% of ASD individuals score a critical minimum of 32 points, whereas only approximately 2% of controls do so. A score of 26 or above has more recently been suggested a useful clinical cut-off with 83% of individuals with ASD scoring 26 or above (Woodbury-Smith, Robinson, Wheelwright & Baron-Cohen, 2005).

It is important to note that the AQ is not a diagnostic instrument like the ADOS-G or ADI-R, but serves as a useful tool to identify behaviours and traits that are indicative of a diagnosis of ASD (for screening purposes in the TD group). The AQ has also been used in the current research to confirm diagnoses of ASD (e.g., Ashwin, Wheelwright & Baron-Cohen, 2006). The measure is especially useful because of its speed of administration (approximately five to ten minutes to complete), and excellent test-retest reliability (Baron-Cohen et al. 2001). The AQ also has good discriminative validity (Woodbury-Smith et al., 2005).

3.4 Participant Matching

The question of how, and on what basis to match participants with ASD and comparison groups is regarded as methodologically difficult (Burack, Iarocci, Flanagan & Bowler, 2004). This is because excessively broad matching criteria will add variability to the data and result in an increased probability of Type I error (a false positive, the probability of finding an ASD-TD group difference when one does not exist). However, excessively stringent criteria will have the opposite effect and increase the probability of making a Type II error (the probability of finding no ASD-TD group difference when one actually exists). There are also practical considerations which can complicate matching further, for example, the availability of resources for matching and the likelihood of finding comparison participants who appropriately match the ASD group on the measures that are deemed important.

Participants can be either individually or group matched. Individual matching involves each ASD participant being matched to a specific comparison participant on a particular measure (e.g., within a given number of points of the performance intelligence quotient, PIQ). Alternatively group matching involves comparing the means of each group (mean PIQ for each group) and confirming that they do not significantly differ from one another using a statistical test such as a t-test or Mann Whitney U test. Each of these methods has strengths and weaknesses, for example, the individual matching method allows increased precision for comparisons of the two groups, meaning the researcher can be more confident that any differences observed are due to

the experimental manipulation rather than variability between groups on matching criteria. However, where more than one variable is important for matching (e.g., matching on gender *and* PIQ) this approach can lead to a loss of data. Therefore group matching on some variables (perhaps those that are less directly related to the research question), can overcome these issues however this approach will inevitably increase the variability between groups.

Intelligence Quotient (IQ) is the most frequently utilised matching variable within cognitive research on individuals with ASD (Mottron, 2004). Several standardised intelligence tests are available; however the most common for adults is the Wechsler Adult Intelligence Scale (WAIS-III, Wechsler, 1999). Matching on measures of Full-scale IQ (FIQ), comprised of Performance IQ (PIQ) and Verbal IQ (VIQ) poses problems for research on individuals with ASD, as typically this population demonstrate a cognitive profile characterised by strengths in PIQ and weaknesses in VIQ relative to TD individuals (Happé 1994b). Often this means that matching can sometimes only be performed on one subtest of IQ. The question of which IQ measures to utilise when matching between groups is central. For example, language is considered an area of difficulty for individuals with ASD (Rapin & Dunn, 2003) whereas visuo-spatial ability is considered a relative strength. This suggests that if groups were matched on language ability, overall the ASD group would be higher functioning than if groups were matched on visuo-spatial ability (Shah & Frith, 1993). The matching variables should therefore be selected on the basis of the research hypothesis (Burack et al., 2004), to ensure that differences in the tasks are not a function of an already existing difference in psychometric test performance.

3.4.1 Matching Criteria for the Present Research

3.4.1.1 Intelligence
Full profiles of intelligence quotient (PIQ, VIQ and FIQ) using the WAIS-III were obtained for each participant. Matching was done using the WAIS-III because it is the most widely used matching measure within cognitive research on individuals with ASD (Mottron, 2004) and is one of the most comprehensive tests available. As the majority of studies were verbal in nature, participants' VIQ and FIQ were individually matched to within 7 points of IQ. Group matching was also done on the basis of PIQ. Concurrent matching on VIQ eliminated the possibility that the TD participants might be at an advantage if PIQ matching alone had been used.

3.4.1.2 Chronological Age (CA)
In the current studies, CA was matched across groups. Participants above the age of 60 years were not included in order to avoid contaminating the memory related differences observed in the ASD group with those related to ageing (for example, see Hedden & Gabrieli, 2004).

3.4.1.3 Gender

An issue that is particularly relevant for matching individuals with ASD to a comparison group is gender. As discussed in Chapter 1, the autism spectrum includes a 3.3:1 ratio of males to females (Baird et al., 2006), and therefore research conducted on individuals with autism generally comprises samples that are predominantly male. For this reason gender was matched across groups for the research presented in the thesis, with a selection bias in favour of males.

3.4.1.4 Recruitment

Participants for Experiment 1 were recruited though a database at the Hôpital Rivière des-Prairies, Montreal. Participants were paid $15/hour (standard rates for research) plus their travel costs, for their participation. Participants for Experiments 2 to 5 were recruited though a database of 77 ASD and 79 TD individuals at City University London. Participants were paid £7/hour (standard university rates) plus their travel costs for their participation.

3.4.1.5 Group Sizes

The number of TD participants to be included in each experiment was determined following previous research studies with similar numbers of ERP stimuli and trials. The researcher aimed to test an ASD group of comparable number to the TD group (individually matched on task-relevant characteristics); however this was not always attainable. ASD participants are not as available for testing as comparison participants / cannot always complete long testing sessions. For the present research, where ASD group sizes are smaller than the TD group, the additional TD participants included in the study are matched to the group's average IQ and age characteristics.

Chapter 4 : RECOGNITION MEMORY OLD-NEW ERP EFFECTS IN ASD

4.1 Experiment 1

4.1.1 Introduction

This experiment aimed to assess word recognition memory Old-New ERP effects in ASD. As explained in the literature review in Chapter 1, individuals with ASD show preserved immediate memory, cued recall (Boucher & Lewis, 1989) and recognition (Barth, Fein & Waterhouse, 1995), but reduced performance on free recall (Bowler, Gaigg & Gardiner, 2010). In addition they are less likely to rely on episodic memory to aid their recognition compared to matched TD individuals despite comparable overall levels of recognition (Bowler, Gardiner & Gaigg, 2007). This pattern raises the possibility that recognition memory in ASD may be supported by neurophysiological processes that differ either quantitatively or qualitatively (or both) from those associated with recognition memory in TD individuals. However, it is still unknown whether this undiminished recognition memory performance comprises qualitatively similar or different neurophysiological mechanisms as in TD. In typical individuals recognition of studied old words show larger positive ERPs from 300 ms post stimulus than those elicited by correctly rejected new words ('Old-New effect', Paller & Kutas, 1992). This experiment sought to test whether the Old-New effect exists in ASD individuals using a word recognition memory test.

Recognition memory studies in healthy aging individuals have shown that recognition is less likely to rely on the episodic memory system (Craik & Anderson, 1999). Recognition in healthy aging, in common with recognition in ASD is characterised by better performance on tasks that provide clues to the studied material (supported tasks, such as cued recall and recognition, Craik and Anderson, 1999) and by a decline in episodic memory (Hedden & Gabrieli, 2004). Typical ageing also resembles ASD in terms of diminished 'theory of mind' (Slessor, Phillips & Bull, 2007) and impaired executive function (Buckner, 2004). Diminished Old-New effects have been identified in ageing individuals (Wolk et al., 2009; Guillaume, Clochon, Denise, Rauchs, Guillery-Girard et al., 2009). In view of the similar patterning of memory performance between ASD and ageing, it was predicted that ASD participants would also show a diminished ERP Old-New effect compared to matched TD individuals, in the context of intact recognition. The question was whether any group-related difference would be limited to quantitative differences between TD and ASD groups (show amplitude differences but similar topography) or if qualitative differences would also be observed (qualitatively different patterns of scalp activity). Quantitative differences would suggest that the cognitive processes deployed to support recognition memory were similar between groups (but different in amplitude). On the other hand

a qualitative difference between groups would suggest both different cognitive processes and neural generators to support recognition memory.

Word frequency was manipulated to ensure participants were using similar recognition processes to complete the task. It was expected that both groups would recognise more low frequency words than high frequency words (in line with Gardiner & Java, 1990; Bowler et al, 2000a), and that the proportion of words correctly recognised would not differ between groups.

4.1.2 Method

4.1.2.1 Participants

Twenty-two participants with ASD (2 females) and 14 TD participants (2 females) took part in the experiment. All participants reported normal or corrected to normal vision. Clinical diagnoses of ASD were confirmed with the ADOS – G and/or ADI-R. Age ranged from 19.25 to 35.08 years in the ASD group, and 20.92 to 35.92 years in the TD group. Participants were recruited from a database at the Hôpital Rivière-des-Prairies, Montreal. Samples were matched on Verbal IQ, Performance IQ and Full IQ using the Wechsler Adult Intelligence Scale III (Wechsler, 1997) and the Wechsler Intelligence Scale for Children – III (Wechsler, 1991), and the data are presented in Table 4.1. Participants were paid standard university rates for their time. The experiment was approved by the ethics committee at City University London and Hôpital Rivière-des-Prairies, Montreal.

	ASD (N=22)		TD (N=14)	
	M	SD	M	SD
Age (years)	25.72	4.76	23.85	3.74
VIQ	106	12	106	12
PIQ	102	13	96	13
FIQ	104	11	102	12

Table 4.1: Mean and standard deviation for Age and IQ measures (WAIS-III or WISC-III) for the TD and ASD groups. VIQ = Verbal IQ, PIQ = Performance IQ, FIQ = Full-scale IQ for Experiment 1.

4.1.2.2 Stimuli

The experimental stimuli were 300 target and 150 lure French words, individually extracted from the Desrochers and Bergeron (2000) corpus of 1,916 French nouns. Half target words and half lure words were of low frequency, (targets: mean = 2.51 ± SEM = 0.12; lures: mean = 2.37 ± SEM = 0.15; $t(223) = 0.69$, *n.s.*), and the other half were of high frequency (targets: mean = 251.92 ± SEM = 13.31; lures: Mean = 254.31 ± SEM = 23.1; $t(223) = 0.096$,

n.s.) according to Baudot frequency index (Baudot, 1992). Low and high frequency target and lure words contained equivalent numbers of syllables (2.18 ± 0.07 and 2.13 ± 0.09 respectively for low frequency target and lure words, and 2.23 ± 0.07 and 2.36 ± 0.14 respectively for high frequency target and lure words; all *t* values < 0.68, *n.s.*) and letters (7.05 ± 0.16 and 7.01 ± 0.24 respectively for low frequency target and lure words, and 6.69 ± 1.56 and 6.85 ± 0.23 respectively for high frequency target and lure words; all *t* values < 0.91, *n.s.*). They were also equated with respect to imageability (the extent to which a word evokes a mental image) on the basis of Desrochers and Bergeron (2000) imagery norms (mean for all words = 4.63 ± 0.07, all t values < 0.89, n.s.). Additional words with similar characteristics were used for the practice block.

4.1.2.3 Presentation

The experiment took place in a dimly lit and sound attenuated laboratory. Participants sat opposite a 17-inch computer screen, with their head restrained with a chin rest at a 60cm viewing distance. Word presentation length varied from 2.5 cm to 11cm and resulted in a minimum visual angle of 2.39° and a maximum viewing angle of 10.47°. Participants completed one practice block and 6 experimental blocks, where each block included a study phase immediately followed by a test phase. The participants were instructed to study the words for a later memory test in which they were to decide whether the test word was presented in the study list or not (i.e., Old/New response).

During the experimental blocks, each study list had 50 items (half low frequency words and half high frequency words), with an additional two buffer items (one buffer item at either end of the study list). At test, the 50 study items and twenty-five lures were presented. The blocks were presented in a random sequence. Words were randomly ordered within blocks and balanced for orthography/syllable length and imageability. During the study phase words appeared at a rate of one every 2000 ms (1400 ms word presentation and 600 ms fixation on a central point measuring 0.8 cm). During the test phase participants were instructed to fixate on a central point for 600 ms, which was replaced by the test word for 2000 ms. The word was then replaced by a fixation cross for 1500 ms, followed by an Old/New response prompt. Participants were told to withhold their responses until the response prompts appeared. Assignment of response categories to keys/hands was counterbalanced across participants.

4.1.2.4 EEG/ERP Acquisition

The electrical brain activity (electroencephalogram, EEG) was continuously recorded from 58 Ag/AgCl scalp electrodes mounted on an easy cap during the test phase. Electrode impedances were kept below 5kΩ. Bipolar electrooculogram (EOG) recordings were made using electrodes placed below and above the dominant eye (vertical EOG), and electrodes placed lateral to each eye (horizontal EOG). Signals from all electrodes were amplified with a bandpass from DC to 100 Hz, digitized at a 1024 Hz sampling rate and online referenced to the left

earlobe. The right earlobe was actively recorded as an additional reference channel.

The data were processed using EEProbe 4, a Linux ERP evaluation package (Nowagk & Pfeifer, 1996). To remain consistent with the majority of research to date (Düzel et al., 1997), the reference was changed offline to the average of the left and right earlobe recordings. Continuous EEG traces were band-pass filtered between 0.3-30 Hz. Prior to averaging EEG data associated with correct responses (hits and correct rejections) were examined for EOG and other artifacts using an automatic rejection procedure. EEG segments of 1900 ms durations (starting 200 ms pre-word onset and lasting 1700 ms post-word onset) were rejected whenever the standard deviation in a 200 ms sliding time-interval exceeded 40 µV in EOG channels or 20 µV in any scalp electrode. Eye blinks were then corrected by subtracting from each electrode the PCA-transformed EOG components, weighted according to VEOG propagation factors (computed via linear regression).

To compute the ERPs, only artifact-free trials to old and new words associated with correct answers were used. Epochs of continuous EEG, including a 200 ms pre-stimulus and 1700 ms post-stimulus period, were averaged from each subject separately for old and new words. ERP difference waves were also computed to examine the magnitude and topographical distribution of Old-New effects in ASD and TD participants.

4.1.2.5 Data Analysis

For behavioural data, proportion of hits (i.e, correct old responses to studied words) and false alarms (FA), (i.e., incorrect old responses to unstudied word) for each ASD and TD participant were calculated for all words. Accuracy scores were corrected for guessing by subtracting the number of false alarms from the number of hits (Hits – FA). This correction method appeals to tradition in recognition memory research in ASD (Bowler et al., 2000a, b, 2007). It is also a non-parametric method of assessing the false alarm rates across groups and consequently can tolerate proportions of hits/false alarm rates at 1 and 0. This is one limitation of d', as it cannot tolerate such values. A' is one possible alternative to the Hits-FA method (however for this data, both the Hits-FA method and A' yielded the same statistical result). To remain consistent with the previous research listed above and to allow comparison of the data gathered from these studies, the Hit-FA method was favoured for all studies in this thesis.

For the electrophysiological results, mean ERP amplitude measures were computed at each scalp electrode using five time-windows: 300-500 ms, 400-800 ms, 800-1000 ms, 1000-1200 ms and 1200-1700 ms encompassing the latency periods of the mid-frontal Old-New effect, the parietal Old-New effect and the late frontal effect, consistent with the old/new ERP effects

reported in previous studies (e.g., Curran, 2000; Duzel et al., 1997). These measurements were performed on the ERP averages for old and new words, both collapsed for low and high frequency words.

To reduce Type 1 error as result of multiple comparisons, electrodes were clustered into five bilateral and three midline scalp regions of interest (following Curran, 2004, 2000; Curran and Cleary, 2003); left and right fronto-temporal (AF7/F7/F5/FT7/FC5, and AF8/F8/F6/FT8/FC6), left and right frontal (AF3/F1/F3/FC1/FC3, and AF4/F2/F4/FC2/FC4), left and right temporal (T7/C5/C3/TP7/CP5, and T8/C6/C4/TP8/CP6), left and right parietal (CP1/CP3/P3/P1, and CP4/CP2/P2/P4), left and right occipito-temporal (P7/P5/PO7/PO3, and P8/P6/PO8/PO4), and midline frontal (Fpz/Fz/FCz), central (C1/Cz/C2/CPz), and parieto-occipital regions (Pz/Poz/O1/O2/Oz).

The magnitude and scalp distribution of Old-New ERP effects between groups were assessed on the ERP difference waveforms (Old minus New amplitudes). To ensure that topographic comparisons of ERPs were not confounded by differences in the magnitude of the Old-New effect, significant interactions involving Region by experimental, and/or by group factors were further investigated after vector-length normalization of the ERP amplitudes measurements (McCarthy & Wood, 1985).

4.1.3 Results

4.1.3.1 Behavioural Results

The raw data and corrected scores for the ASD and TD groups are presented in Table 4.2. The behavioural data were analysed using a 2 word Frequency (High/Low) x 2 Group mixed Repeated Measures ANOVA. There was no significant difference in the corrected recognition scores ($F_{(1, 34)} = 0.47$, p = n.s., mean recognition in the TD group was 0.56 and ASD group was 0.61). There was a main effect of word Frequency ($F_{(1, 34)} = 45.58$, p<.01) where recognition was greater for low frequency words compared to high frequency words. There was no word Frequency x Group interaction ($F_{(1, 34)} = 0.10$, p = *n.s.*) demonstrating that both groups recognised more low frequency than high frequency words). Both groups recognised a similar proportion of false alarms ($F_{(1, 34)} = 0.004$, p = *n.s.*), and both groups also made more false alarm judgements to high frequency (M = 0.15, SD = 0.14) than low frequency words (M = 0.10, SD = 0.10), ($F_{(1, 34)} = 14.05$, p<.01).

| | TD (N=14) | | | | ASD (N=22) | | | | Both Groups (N=36) | | | |
| | High | | Low | | High | | Low | | High | | Low | |
	M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Hits	0.64	0.17	0.72	0.18	0.68	0.16	0.79	0.10	0.66	0.16	0.76	0.14
FA	0.15	0.13	0.10	0.07	0.14	0.15	0.11	0.12	0.15	0.14	0.10	0.10
Hits-FA	0.49	0.20	0.62	0.23	0.53	0.24	0.68	0.17	0.51	0.22	0.66	0.19

Table 4.2: Mean and standard deviation of recognition accuracy scores (proportions) for high and low frequency words for TD and ASD groups in Experiment 1.

4.1.3.2 ERP Results

As there were no between group differences in the number of high and low frequency words recognised, the ERP trials corresponding to low and high frequency words were collapsed. The following analyses of the electrophysiological data were conducted to investigate Old-New potential differences between ASD and TD groups. The mean number of artifact-free trials with correct answers included for the ERP averaging of old and new words did not differ between the two groups (independent samples *t*-tests (34) < 0.94; both p's > .3). TD group Old = 79, New = 50; ASD group Old = 85, New = 51.

Description of ERP waveforms

The ERP waveforms to Old and New words are shown at nine electrode locations in Figure 4.1, and are presented separately for the ASD and TD groups. For both groups, there were consistent ERP amplitude differences between old and new words, with old words eliciting greater positive ERP voltages than new words (Old-New ERP effect). The data were analysed in time windows following previous research (Curran, 2000; Düzel et al., 1997; Wolk et al., 2009), these were, 300-500 ms, 400-800 ms, 800-1000 ms, 1000-1200 ms and 1200-1700 ms. Figure 4.2 displays 2D scalp distributions of the Old-New ERP differences in these time windows for TD and ASD groups.
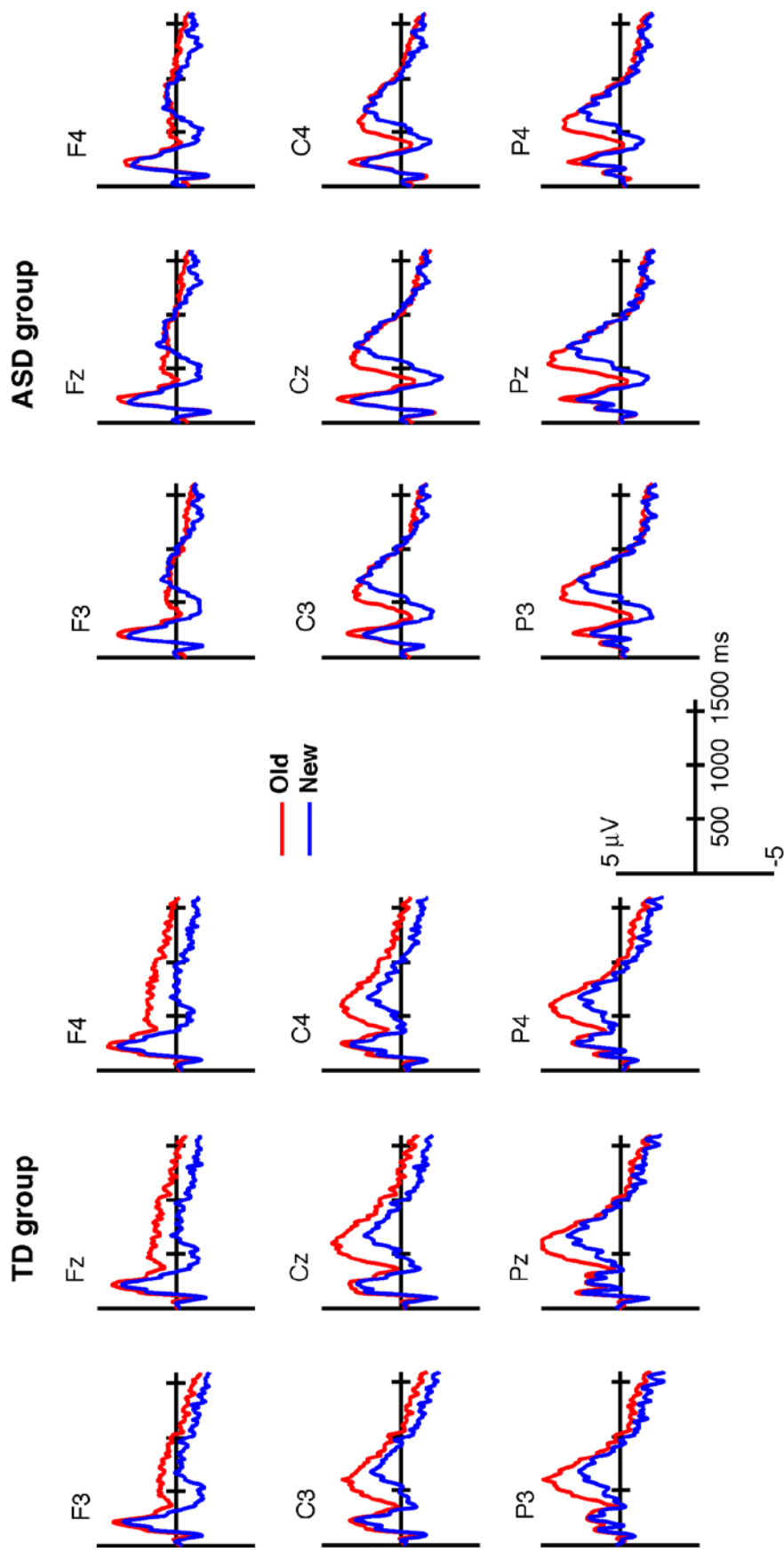
Figure 4.1:: ERP Old-New effects or TD (N=14) and ASD (N=22) groups shown at nine selected electrodes. Old word ERPs are presented in red New word ERPs in blue

The Old-New ERP effects in TD participants were characterized by three spatially and temporally different ERP effects (see Figure 4.2), consistent with the Old-New ERP effects reported in previous studies (Curran, 2000; Düzel et al., 1997; Wolk et al., 2009): a mid-frontally distributed Old-New ERP effect in the 300-500 ms time-window (mid-frontal Old-New effect), a parietal Old-New ERP effect in the 400-800 ms time-window (parietal Old-New), followed by a long-lasting right-frontal Old-New ERP effect in the 800-1700 ms time window (late frontal Old-New). The Old-New ERP effects, displayed striking topographical differences in the ASD group. More specifically, the Old-New effect in the ASD group had a left parietal distribution during the time-range of the mid-frontal Old-New effect (300-500 ms). The Old-New effect between 400 and 800 ms was parietal in ASD participants, similar to TD participants. The late frontal Old-New effect was also markedly reduced in the ASD group.

ERP Analysis

These effects were statistically assessed using repeated measures ANOVAs with Group as between-subjects factor and Old-New, Region and Laterality (for measures computed on the 5 lateral regions) as within-subjects factors, performed separately for each time-window of interest: in the 300-500 ms (mid-frontal Old-New effect), 400-800 ms (parietal Old-New), 800-1000 ms, 1000-1200 ms and 1200-1700 ms (late frontal Old-New) time-windows. Greenhouse-Geisser corrections are reported where sphericity is violated. The initial analyses were made with within subjects factors of 'Latency', 'Region' and 'Old-New' and a between subjects factor of 'Group'. Main effects of Latency and Region are not reported as alone they do not reflect memory related phenomena. The mean and standard deviation amplitudes for each region of interest at each time window can be seen in Table 4.3.

		TD (N=14)		ASD (N=22)	
		M	SD	M	SD
300-500 ms	Left fronto-temporal	1.01	1.07	0.59	0.85
	Right fronto-temporal	1.22	1.06	0.38	0.59
	Left frontal	1.70	1.48	1.05	1.08
	Right frontal	1.70	1.51	0.89	0.89
	Left temporal	0.95	0.90	1.12	0.80
	Right temporal	0.97	0.90	0.81	0.75
	Left parietal	1.26	1.28	1.47	1.04
	Right parietal	1.19	1.18	1.24	1.08
	Left occipito-temporal	0.56	0.78	1.21	0.94
	Right occipito-temporal	0.61	0.72	1.03	0.97
	Midline frontal	1.83	1.53	0.86	0.96
	Central	1.65	1.53	1.42	1.08
	Parieto-occipital	0.65	0.93	1.17	1.04

400-800 ms	Left fronto-temporal	1.10	1.17	0.46	0.89
	Right fronto-temporal	1.45	1.24	0.44	0.72
	Left frontal	1.97	1.83	1.12	1.08
	Right frontal	2.14	1.85	1.11	0.99
	Left temporal	1.48	1.23	1.30	1.00
	Right temporal	1.51	1.22	1.13	1.11
	Left parietal	2.09	1.76	1.91	1.24
	Right parietal	2.02	1.59	1.77	1.35
	Left occipito-temporal	1.37	1.07	1.57	0.94
	Right occipito-temporal	1.24	0.91	1.38	1.17
	Midline frontal	1.96	1.82	1.01	0.86
	Central	2.39	2.20	1.85	1.21
	Parieto-occipital	1.37	1.13	1.52	1.10
800-1000 ms	Left fronto-temporal	0.63	1.59	-0.05	0.81
	Right fronto-temporal	1.09	1.44	0.10	1.03
	Left frontal	1.08	1.97	-0.13	1.02
	Right frontal	1.46	1.99	0.04	1.27
	Left temporal	0.68	1.25	0.27	0.92
	Right temporal	0.81	1.21	0.28	1.20
	Left parietal	0.67	1.53	0.09	1.17
	Right parietal	0.76	1.49	0.18	1.35
	Left occipito-temporal	0.63	1.23	0.32	1.06
	Right occipito-temporal	0.34	1.03	0.23	1.15
	Midline frontal	1.22	2.05	-0.06	1.22
	Central	1.09	2.10	-0.06	1.18
	Parieto-occipital	0.25	1.13	-0.03	1.17
1000-1200 ms	Left fronto-temporal	0.61	1.47	-0.02	0.89
	Right fronto-temporal	1.02	1.53	0.48	1.25
	Left frontal	0.90	1.90	-0.14	1.18
	Right frontal	1.48	1.87	0.31	1.38
	Left temporal	0.74	1.36	0.15	0.90
	Right temporal	0.79	1.35	0.43	1.13
	Left parietal	0.59	1.81	-0.03	1.06
	Right parietal	0.80	1.68	0.17	1.28
	Left occipito-temporal	0.66	1.38	0.35	0.91
	Right occipito-temporal	0.32	1.24	0.47	1.10
	Midline frontal	1.19	1.87	0.04	1.39
	Central	1.05	2.15	-0.14	1.30
	Parieto-occipital	0.26	1.38	0.19	1.10
1200-1700 ms	Left fronto-temporal	0.55	1.72	0.43	1.10
	Right fronto-temporal	0.99	1.54	0.84	1.41

Left frontal	0.78	2.10	0.43	1.32
Right frontal	1.38	2.03	0.71	1.48
Left temporal	0.85	1.54	0.38	1.04
Right temporal	0.87	1.46	0.51	1.10
Left parietal	0.72	1.83	0.19	1.09
Right parietal	0.81	1.86	0.31	1.23
Left occipito-temporal	0.67	1.30	0.25	1.00
Right occipito-temporal	0.34	1.38	0.31	0.99
Midline frontal	0.93	2.11	0.57	1.53
Central	1.04	2.35	0.23	1.29
Parieto-occipital	0.32	1.44	0.13	0.97

Table 4.3 Means and standard deviations for the amplitude differences at each region of interest in the TD and ASD groups for Experiment 1. Amplitude measures are in µV.

A significant main effect of Old-New was identified ($F_{(1,34)}$ =27.91, $p < .05$) which was qualified by a significant Old-New by Latency interaction ($F_{(3.04, 103.31)} = 15.78$, $p < .05$). The Old-New by Region interaction was significant ($F_{(3.43, 116.67)} = 3.18$, $p < .05$), which also differed between groups ($F_{(3.43, 116.67)} = 3.56$, $p < .05$). There was an Old-New by Latency by Region interaction ($F_{(8.23, 279.91)} = 6.18$, $p < .05$) which also interacted with Group, ($F_{(8.23, 279.91)} = 2.05$, $p < .05$). As the Old-New effect differed across Latency intervals, repeated measures ANOVAs were run for each time window in order to unravel this complex pattern of interactions.

300-500 ms

From 300-500 ms there was a significant Old-New effect $F_{(1,34)} = 55.05$, $p < .05$), and a significant Old-New by Region interaction ($F_{(3.05, 103.69)} = 6.69$, $p < .05$). The Old-New by Region by Group interaction was also significant ($F_{(3.05, 103.69)} = 7.22$, $p < .05$), where the Old-New effect was largest at anterior locations in the TD group but left posterior regions in the ASD group.

400-800 ms

From 400-800 ms there was a significant Old-New effect $F_{(1, 34)} = 61.32$, $p < .05$) and Old-New by Region interaction ($F_{(3.05, 119.32)} = 13.42$, $p < .05$), with the largest effects being observed over parietal regions. In addition, the Old-New by Region by Group interaction was significant ($F_{(3.05, 119.32)} = 4.71$, $p < .05$), where the effect was diminished at anterior regions in the ASD group.

800-1000 ms

From 800-1000 ms, there was a main effect of Old-New ($F_{(1, 34)} = 6.27$, $p < .05$) and an Old-New by Group interaction $F_{(1, 34)} = 4.02$, $p = .05$) where the Old-New effect was markedly diminished in the ASD group (mean voltage amplitude difference at each region for TD individuals = 0.82µV, for ASD individuals = 0.09 µV).

1000-1200 ms

From 1000-1200 ms the Old-New effect was significant ($F(1, 34) = 6.27$, $p < .05$). There was also an Old-New by Region by Group interaction ($F(3.42, 116.26) = 2.55$, $p = .05$) where the effect was markedly diminished at right and midline anterior and anterior-temporal regions in the ASD group.

1200-1700 ms

Lastly, from 1200-1700 ms the Old-New effect was present ($F(1,34) = 8.02$, $p < .05$), and there was an Old-New by Region interaction, which showed that the Old-New effect was largest at right anterior regions ($F(3.43, 116.44) = 2.71$, $p < .05$).
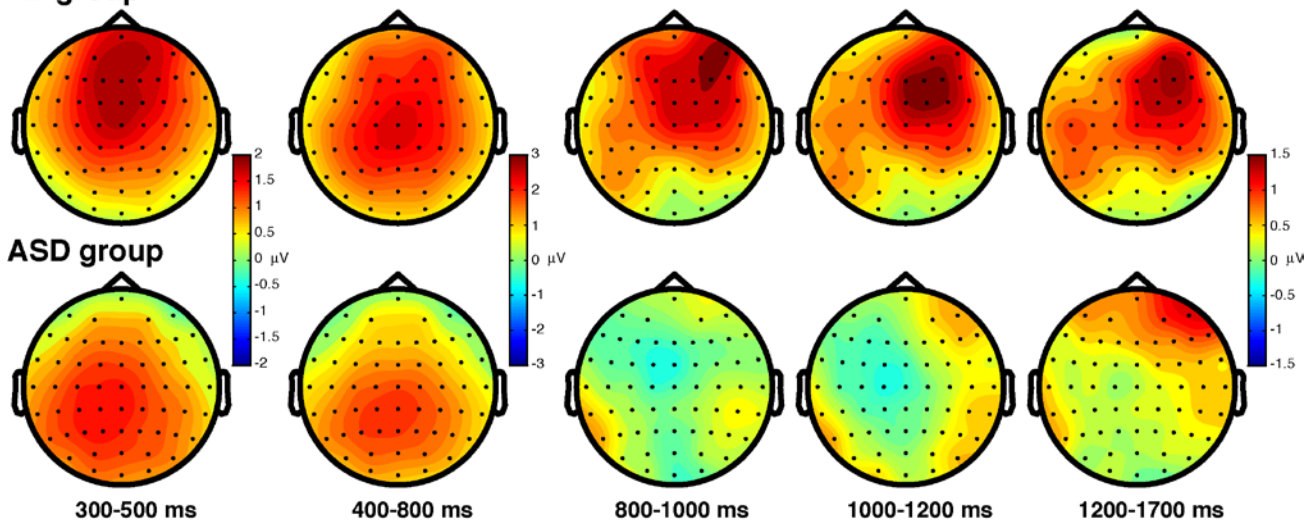
Figure 4.2: 2D scalp distributions of Old-New mean ERP amplitude differences (Old minus New words) in the 300-500 ms, 400-800 ms, 800-1000 ms, 1000-1200 ms and 1200-1700 ms time windows for TD (N = 14) and ASD (N = 22) individuals in Experiment 1.

In line with existing research (Wolk et al., 2009; Rugg & Curran, 2007; Curran, 2000), the Old-New ERP effects from 300-1700 ms in TD participants were characterized by: a mid-frontally distributed Old-New ERP effect in the 300-500 ms time-window (mid-frontal Old-New effect), a parietal Old-New ERP effect in the 400-800 ms time-window (parietal Old-New), followed by a long-lasting right-frontal Old-New ERP effect in the 800-1700 ms time window (late frontal Old-New). Despite the comparable behavioural performance between groups, there were underlying neural differences. An Old-New effect from 300-500 ms was present in the ASD group but had a left parietal distribution. The Old-New effect between 400 and 800 ms was parietal in ASD participants, similar to TD participants. The late frontal Old-New effect was absent in the ASD group.

4.1.4 Discussion

The aim of the present experiment was to investigate the nature of memory processing

atypicalities in autism using behavioural and ERP measures. In line with previous studies (Bowler et al., 2000a, b, 2007), behavioural findings revealed no overall difference between ASD and TD groups in the proportion of words recognised. In addition, both participant groups showed a recognition memory advantage for low frequency words (Glanzer & Bowles, 1976; Guttentag & Carroll, 1994), that is, better recognition accuracy for low frequency words than for high frequency words suggesting that both groups were using similar processes to support recognition memory. However, this behavioural sparing was not consistent with the patterning of ERPs in the ASD participants. The patterning reported in the present study replicated previous findings in TD individuals of long duration Old-New effects and identified differences in the amplitude and scalp topography of the effect for ASD individuals. The distinct patterning of activity observed for this population shows that their undiminished recognition memory performance results from different underlying brain activity. This the first study to demonstrate differences in the Old-New effect for ASD individuals.

Topographical differences in the Old-New effect were observed between groups from 300-500 ms, 400-800 ms and 1000-1200 ms. TD individuals showed an anterior onset (300-500 ms) whereas for ASD individuals the focus was at left posterior and parietal regions. The topographical differences observed from 400-800 ms showed that the Old-New effect in ASD retained its posterior maximum but for TD individuals was more widespread with an anterior focus. The Old-New effect was attenuated from 800-1000 ms in the ASD group, but showed right and midline anterior and anterior temporal positivity in the TD group. To sum up, the parietal focus of activity from 300-800 ms in the ASD group contrasts with joint frontal and parietal activity for TD individuals and suggests that recognition in ASD individuals may engage a single memory system as opposed to the two engaged by TD individuals.

At present, we can only speculate on the reasons behind the differing patterns of Old-New effects in ASD and TD individuals. A strong contender for explaining the difference is the episodic/semantic distinction made by Tulving (1985a, b) in relation to recognition memory. The findings reported above are in line with the suggestion that individuals with ASD are engaging one memory system (as shown by the parietal focus of the Old-New effect in ASD) rather than two (mid frontal Old-New effects followed by parietal Old-New effects in TD). On the basis of earlier reports of diminished episodic Remember judgements and relatively spared semantic Know judgements in ASD (Bowler et al., 2000a, b, 2007), one suggestion for the distinct patterning of the Old-New effect in ASD, is that it results from recognition processes that are less reliant upon the episodic memory system, and more reliant upon the semantic memory system. As has been reviewed in Chapter 1, TD individuals demonstrate parietal Old-New effects for Remember judgements (from 400-800 ms) and mid-frontal Old-New effect for Know judgements (from 300–500 ms). The diminished Old-New effect for ASD individuals found here, suggests

that this group engage fewer cognitive processes during a time window that directly follows Remember judgements in TD individuals. Furthermore the topographical differences observed in the ASD group from both 300-500 ms and 400-800 ms suggest that both the semantic and episodic memory systems are engaging partially different neural generators compared to those engaged by TD individuals.

To summarise, the mid-frontal Old-New effect observed for the TD group was absent for ASD individuals, who instead showed a posterior and parietal focus. This finding provides evidence to suggest that semantic Know memory judgements may not be performed typically in ASD. Moreover, parietal activity was observed for the ASD group from 400-800 ms; however activity for the TD group was more widespread, including anterior positivity. This implies that rather than recognition being supported by early Old-New effects that are associated with Knowing in TD, recognition in ASD seems to be exclusively associated with later parietal Old-New effects that have been linked with Remembering in typical development. Although these later parietal effects are diminished in ASD, given the behavioural evidence of diminished Remember and preserved Know responses (Bowler et al., 2000a, b, 2007), this finding is paradoxical since it implies that the neurophysiological correlates of semantic rather than episodic processes are compromised. This is precisely the opposite of what has been concluded on the basis of behavioural evidence. The caveat in this case is that both Remember and Know judgments fed into overall recognition Old-New effects recorded in this study, rendering the foregoing conclusions speculative. Nevertheless these findings show that intact behavioural recognition in ASD is underpinned by qualitatively and quantitatively different patterns of neural activity. To explore this further, the two experiments reported in Chapter 5 were designed to isolate ERP Old-New effects associated with episodic Remember and semantic Know judgements using the Remember/Know paradigm.

Chapter 5 NEURAL CORRELATES OF AUTONOETIC AND NOETIC CONSCIOUS AWARENESS IN ASD

5.1 Overview

Previous studies have revealed a diminished episodic memory in ASD with an increased reliance upon the semantic memory system (Bowler et al., 2000a, b, 2007). Tulving (1985b) argues that the episodic memory system is characterised by autonoetic conscious awareness, a type of awareness that allows an individual to mentally travel back in time to re-experience a past episode. Semantic memory on the other hand, is characterised by noetic conscious awareness, allowing the individual to 'know' something from the past, without remembering any contextual detail (such as a timeless fact). These findings suggest a diminished episodic memory and autonoetic conscious awareness, but preserved semantic memory and noetic awareness in ASD.

Experiment 1 revealed two main differences in the Old-New effect between ASD and TD participants. First, differences were observed in the topography of the Old-New effect from 300-800 ms where a left parietal and posterior focus in ASD contrasted a frontal focus in TD. Second, the parietal focus post 800ms was markedly diminished in amplitude in ASD. The diminished Old-New effect in ASD post 800 ms, occurs in a time window that directly follows Remember Old-New effects reported for TD individuals (see Rugg & Curran, 2007). Together with the observation of fewer topographical differences from 400-800ms, this may indicate that the processes underlying episodic Remember judgements and autonoetic conscious awareness are quantitatively diminished but qualitative relatively preserved in ASD. Experiment 1 however reports these differences within overall recognition rather than Remember and Know judgements separately. The aims of Experiments 2 and 3 were to investigate these ERPs in ASD by isolating autonoetic and noetic conscious awareness using the Remember/Know paradigm. Experiment 2 sought to replicate previous findings of diminished autonoetic conscious awareness in ASD in a behavioural Remember/Know memory test that could be adapted for an ERP setting. This study formed the basis for Experiment 3, an ERP study to isolate the ERP correlates for true and false, autonoetic and noetic conscious awareness in ASD.

5.2 Experiment 2

5.2.1 Introduction

The aim of Experiment 2 was to confirm previous behavioural findings of diminished episodic memory in ASD (Bowler et al., 2000a, b, 2007). The Remember/Know paradigm (Gardiner and Java, 1990) was used to tease apart the relative contributions of episodic and

semantic memory systems (and autonoetic and noetic conscious awareness respectively) to recognition memory in ASD. The task involves presenting participants with a list of words, after which they take part in a recognition memory test. Participants are asked to introspect and expand on the phenomenology of their memories for the recognised words and specify whether they 'Remember' or 'Know' the word appeared. 'Remembering' the occurrence of the word in the study list, implies that participants are able to Remember something specific about the time the word was presented, thus involving a conscious awareness of the self in subjective time. 'Knowing' that a word had appeared during study on some other basis is void of any information relating to the study episode in which the word was studied and is therefore thought to index contributions made from the semantic memory system, which involves noetic awareness.

According to Perner (1991), during a typical developmental trajectory, the episodic memory system is the last memory system to emerge, usually at around 3 to 4 years of age. Perner argues that in order to fully develop this episodic memory system an individual must be able to represent an event from the past, and also represent the event as personally experienced (represent themselves from an earlier time point). This is only possible once a child has understood the representational nature of memories, which implies a "theory of mind" and the ability to understand ones own and others' mental states. Failure to develop a "theory of mind" has been implicated in children with ASD using theory of mind tasks (Baron-Cohen et al., 1985), suggesting an impaired episodic memory system in ASD. Adults with ASD typically pass these types of tasks, but it has been suggested that they solve these problems using cognitive routes, called "hacking-out" (Happé, 1995). If this were to be the case, the impairment in autonoetic conscious awareness and episodic Remembering observed in studies using the Remember/Know paradigm in ASD may be a conservative estimate of the episodic memory deficit, because 'Remembering' may be compensated with processes are thought to mediate 'hacking out'. In turn, these compensatory cognitive processes may be the source of the unusual ERP Old-New effects observed in Experiment 1. To address this issue directly, it is necessary to assess Old-New effects separately for Remembering and Knowing. Experiment 2 set out to replicate previous behavioural findings of attenuated Remembering in ASD using a paradigm that lends itself for adaptation to an ERP setting.

Experiment 2 was based on a study by Bowler et al. (2000s) but the procedure was modified to allow adaptation to an ERP setting in two ways. First, in the original study, participants made verbal responses which were recorded by the experimenter. As the ERP Old-New effects of interest occur after stimulus presentation, the verbal response made by the participants would create movement artifacts that would interfere with recordings. To minimise these artifacts, participants were asked to withhold their response until a screen appeared and to respond using button presses rather than verbally. Second, participants were not asked for

qualitative Remember and Know descriptions after each response (as in the original study), this would not have been practical with such a large sample of words. It was therefore decided to include one full length practice block in which verbal feedback from participants was assessed.

In terms of the EEG recording, it was important to consider accuracy versus speed trade-offs made by participants. Rotello and Heit (2000) have demonstrated that time restrictions placed on participants as they make Remember and Know judgements influences their response judgements. Participants are more likely to respond 'Know' if there is a short time restriction compared to when there is not. To avoid confounding the behavioural results with an emphasis on the speed of response, participants were instructed to make first accurate then speeded decisions to stimuli. Last, to avoid contamination of the ERPs with visual off-responses (responses in the EEG trace when a stimulus is replaced with a smaller fixation cross) the stimuli remained on screen until the participant had made their response judgments, after which a fixation cross appeared and a new stimulus was presented.

Word frequency was manipulated as in the original Bowler et al. (2000a) study to allow comparisons between ASD and TD individuals on Remember/Know recognition for high and low frequency words. As in Experiment 1, this manipulation was employed to ensure that recognition memory at the behavioural level operates similarly in ASD and TD participants, at least with respect to how recognition memory is affected by properties of the to-be-remembered stimuli. Thus, it was predicted that the proportion of correctly recognised words would be greater for low frequency words compared to high frequency words and that this would be the same for ASD and TD participants. Further the enhanced recognition judgements made for the low frequency words were expected to be of the type 'Remember' as found in previous studies (Gardiner & Java 1990; Gardiner, Richardson-Klavehn & Ramponi 1997). The main predictions were that overall recognition scores would be comparable across the two groups, but that recognition in the ASD group would comprise fewer episodic-remember responses, with an increased number of semantic-know responses.

5.2.2 Method

5.2.2.1 Participants

Twenty-three ASD participants (6 females) and 22 TD participants (5 females) took part in the experiment and were recruited through a database at City University London. The ASD group all had a clinical diagnosis which was confirmed with the ADOS-G. All participants met DSM criteria for the Autism Spectrum Cut off on the ADOS-G, and 4 participants also had an ADI confirmation. Autism Spectrum Quotient (AQ) data were also collected from ASD and TD individuals. The ASD group were individually matched to the TD group on Verbal, Performance

and Full Scale IQ, measured using the Wechsler Adult Intelligence Scale- Revised (WAIS-R; Wechsler 1981 and WAIS-III-UK 1999) and Age, (see Table 5.1). The experiment was approved by the ethics committee at City University London.

	ASD (N=23)		TD (N=22)	
	M	SD	M	SD
Age (years)	37.42	12.79	42.19	11.61
AQ	34	8	17	7
VIQ	107	13	110	16
PIQ	106	17	106	18
FIQ	107	16	109	17

Table 5.1: Mean and standard deviation for Age, AQ and IQ measures (WAIS-III or WAIS-III-R). VIQ = Verbal IQ, PIQ = Performance IQ, FIQ = Full-scale IQ for Experiment 2.

5.2.2.2 Stimuli

A list of 96 words was used, comprising 48 low frequency words and 48 high frequency words, gathered from the Medical Research Council Psycholinguistic database (Coltheart, 1981), with mean frequency counts of 2 (SD = 0.10), and 160 (SD = 1.6) words per million respectively on the Kucera-Francis written frequency norms. The high and low frequency word lists were matched on imagability ratings (Coltheart, 1981), which ranged between 100 and 700 in both lists (mean high frequency = 609, SD = 19.9; mean low frequency 609, SD = 18.2). High and low frequency words were also matched on number of syllables such that there were equal numbers of one, two and three syllable words.

The 96 words were split into 2 lists of 48 words, list A and list B. Each list comprised 24 high frequency words and 24 low frequency words. Participants studied either list A or list B during a study phase. During the test phase, all 96 words were presented (48 studied words and 48 new words).

5.2.2.3 Presentation

Each participant was tested individually, presented with written instructions and completed a practice block prior to the task. During the study phase the 48 words were presented on a computer screen in a random order, one at a time in upper case lettering. Words remained on screen for 2000 ms with 1000 ms inter-stimulus interval. Participants were instructed to memorise the words during the study phase for a later memory test. At test, all 48 study words were presented with 48 new words. Words appeared on the screen one at a time. After each word a response prompt appeared and remained on screen until the participant made

their response. For each word the participant was asked to make a Yes/No recognition judgement by means of a button press. For each word the participant recognised they were asked to indicate if they could also remember something specific about the time they studied the word (Remember response), or if they just knew it had appeared during the study phase (Know response). Instructions for the Remember/Know judgements given to participants were as follows:

If you 'REMEMBER' the word, this means you should remember something about when you actually saw the word. For example you may remember where it was on the list, you may remember the word flashing up on the screen or you remember something you imagined as a result of seeing the word. If you remember a word being on the list you should also remember something about the time that you saw it.

Alternatively you may 'KNOW' the word was presented on the study list, but not remember anything about the time at which you saw the word. For example, you may not remember details or any imagery that came to mind after seeing the word, but may KNOW it appeared on the list.

Each ASD participant and their matched TD participant were presented with the same version of the task (there were 4 versions of the task in order to counterbalance the button responses). Participants were asked to make accurate and speeded judgements to each word (accuracy was emphasised over speed). The task lasted approximately 10 minutes in total depending on the speed of responses given by participants.

The practice trial served as a check to ensure participants fully understood the Remember/Know distinction. After participants had completed the practice, they were asked to write down examples of the Remember and Know responses they had given during the practice block. The experimenter continued with the task once she was sure the criteria for Remember/Know judgements used by participants were accurate. Examples of Remember and Know judgements given by TD and ASD participants can be seen in Appendix 1. These descriptions appear qualitatively indistinguishable between groups.

5.2.3 Results

The data for the TD and ASD groups are presented in Table 5.2. Following standard procedure, the recognition scores were analysed using corrected proportion scores (proportion of correct hits – false alarms). The corrected data were subjected to a 2 (Group) x 2 (High/Low word frequency) x 2 (Remember/Know) Repeated Measures ANOVA, with Group as a between

subjects factor.

	TD (N=22)				ASD (N=23)				Both Groups (N=45)			
	High		Low		High		Low		High		Low	
	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD
Hits												
R	0.52	0.19	0.67	0.20	0.36	0.26	0.43	0.29	0.43	0.24	0.54	0.28
K	0.16	0.11	0.18	0.11	0.29	0.24	0.26	0.20	0.23	0.20	0.22	0.16
R+K	0.68	0.16	0.84	0.15	0.65	0.36	0.69	0.22	0.66	0.28	0.76	0.20
FA												
R	0.06	0.11	0.03	0.06	0.03	0.09	0.02	0.04	0.05	0.10	0.02	0.05
K	0.07	0.09	0.05	0.09	0.08	0.12	0.07	0.09	0.07	0.10	0.06	0.09
R+K	0.13	0.17	0.08	0.12	0.12	0.13	0.09	0.09	0.12	0.15	0.08	0.10
Hits-FA												
R	0.46	0.24	0.63	0.22	0.32	0.26	0.42	0.28	0.39	0.26	0.52	0.28
K	0.10	0.10	0.12	0.13	0.22	0.24	0.19	0.19	0.15	0.19	0.15	0.17
R+K	0.55	0.25	0.76	0.22	0.53	0.39	0.60	0.23	0.54	0.33	0.67	0.24

Table 5.2 : Mean and standard deviation of recognition accuracy scores (proportions) for high and low frequency words for TD and ASD groups in Experiment 2. R = Remember, K = Know, Hit = Correctly recognised Old word, FA = Incorrectly indorsed Lure word.

Overall recognition scores did not differ between groups ($F_{(1, 43)}$ = 1.31, p > .05). In line with previous findings, there was a main effect of word Frequency ($F_{(1, 43)}$ = 18.29, p<.01), with low frequency words being more likely to be recognised than high frequency words (Gardiner & Java, 1990; Gardiner et al., 1997; Bowler et al., 2000a). There was also a main effect of Remember/Know with participants being more likely to give a Remember response than a Know response ($F_{(1, 43)}$ = 46.83, p< .01). The two way interaction between Group (ASD/TD) and response type (Remember/Know) was significant ($F_{(1, 43)}$ = 9.217, p<.01) with both the ASD and TD group being significantly more likely to report a Remember than Know response but with a much larger difference in the TD group than in the ASD group. Independent *t* tests revealed that Remember responses were significantly greater for TD individuals compared to ASD individuals ($t_{(43)}$ = 2.51, p< .05), and Know responses were significantly greater for ASD individuals compared to TD individuals ($t_{(43)}$ = -2.10, p< .05). These results confirm previous findings of diminished Remember responses and increased Know responses for ASD individuals compared to TD individuals (Bowler et al., 2000a, b, 2007, see Figure 5.1).
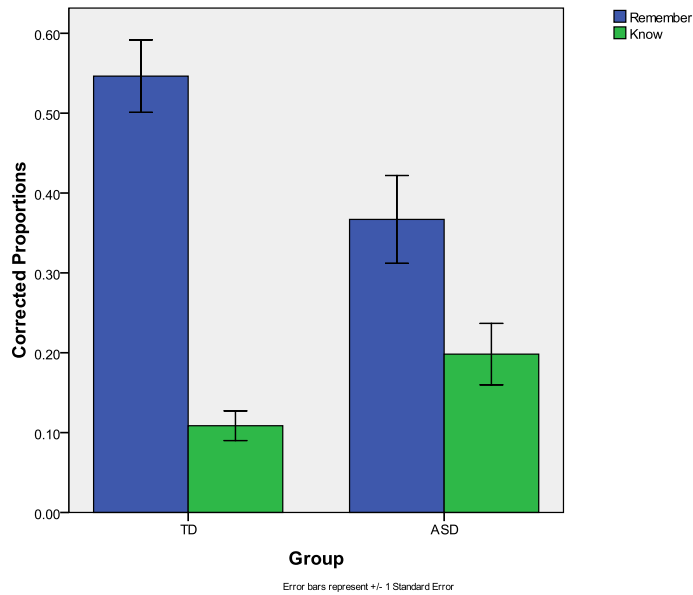
Figure 5.1 : Mean proportions of Remember and Know judgements given by TD and ASD groups for Experiment 2.

The two way interaction between Remember/Know and word Frequency was also significant (F (1, 43) = 10.49, p< .01). Remember responses were significantly greater for the low frequency words than for the high frequency words (*t* (44) = 5.73, p<.01) whilst Know judgements were comparable across high and low frequency words (*t* (44) = -0.02, p = *n.s*, see Figure 8.2).
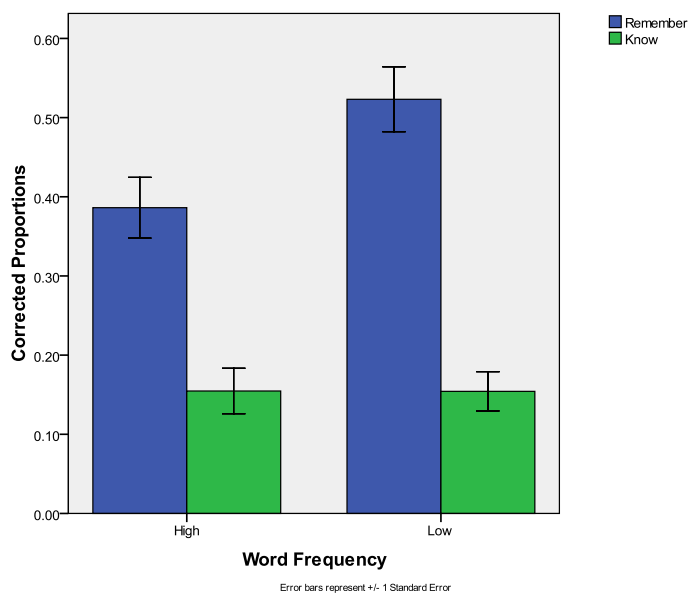
Figure 5.2: Mean proportions of Remember and Know judgements for high and low frequency words for Experiment 2.

Unexpectedly, given the findings of Experiment 1, the Group by Word Frequency interaction was also significant (F (1, 43) = 4.16, p<.05, see Figure 5.3). Separate analyses for each group revealed that low frequency words were more often recognised than high frequency words in the TD group (F (1, 21) = 36.33 p< 0.01), but there was no difference in recognition proportions for low and high frequency words in the ASD group (F (1, 22) = 1.776, p = *n.s*). Importantly, however, there was no 3-way Frequency x Remember/Know x Group (F (1, 43) = 0.73, p = *n.s.*) interaction, which shows that word frequency had similar effects on Remember and Know judgements in both groups. Within group analyses further confirmed this conclusion since participants in both groups were more likely to 'Remember' low than high frequency words (TD group: F (1, 21) = 6.30, p< .05; ASD group: F (1, 22) = 4.33, p<.05) whilst 'Know' judgements were comparable across high and low word frequencies. Thus, although word frequency affected overall recognition rates differently, the manipulation seemed to have similar effects on semantic and episodic memory judgements in the two groups.
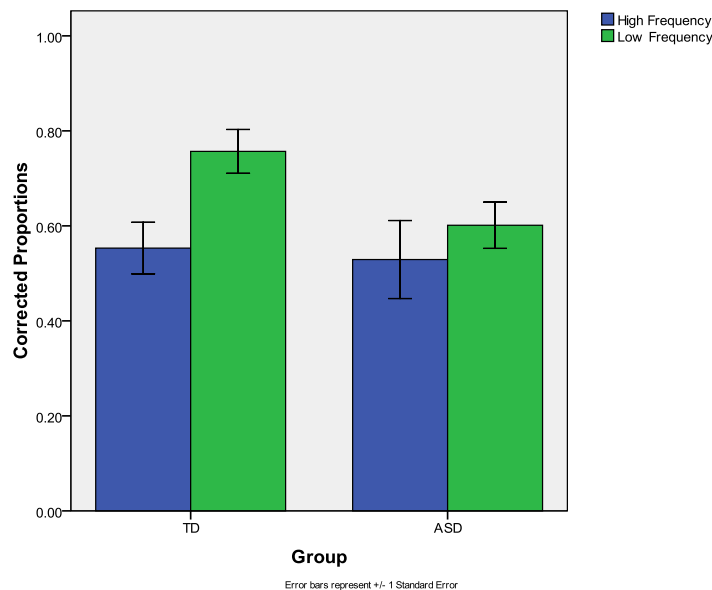
Figure 5.3: Mean proportions of high and low frequency words recognised by TD and ASD groups for Experiment 2.

5.2.4 Discussion

The results of this experiment confirmed that overall recognition did not significantly differ between groups, but recognition in the ASD group was characterised by fewer episodic Remember judgements and more semantic Know judgements (Bowler et al., 2000a, b, 2007; Tanweer et al., 2010). The results support previous claims that recognition in the ASD group is characterised by diminished episodic Remember responses and autonoetic conscious awareness, but a moderate increase in the number of semantic Know responses and noetic

awareness. Following Tulving (1983, 1985b) these results would suggest a specific impairment in the recall of the spatial and temporal context in which the study word was first encountered.

Bowler et al. (2000a) found that low frequency words were more likely to be recognised than high frequency words in both ASD and TD individuals, a finding that demonstrates that both groups were completing the task using similar encoding and retrieval processes. This finding was replicated in Experiment 1 but not Experiment 2. According to (Gardiner & Java, 1990) the increased recognition rate for low frequency words denotes an increase in the contextual detail with which these words are encoded during the study phase. In line with this suggestion, the increased recognition rate for low frequency words has been found to be primarily reflected in Remember rather than Know recognition judgements (Gardiner & Java, 1990; Gardiner, Richardson-Klavehn & Ramponi 1997). In the present experiment, and in line with previous findings, TD individuals showed significantly greater recognition for low frequency words compared to high frequency words, and these words were more likely to be judged as Remembered than Known. However, the ASD group demonstrated an overall recognition rate that was comparable for both low and high frequency words. Since Remembering is predominant for low frequency words, an impairment in episodic memory would be expected to result in overall fewer recognitions of low frequency words. Conversely, as Knowing is typically associated with high frequency words, an enhanced Semantic memory would lead to higher recognitions for low frequency words in the ASD group. The Remember/Know by Group interaction shows that ASD is characterised by impaired episodic but enhanced semantic memory, which would be expected to reduce the overall frequency effect for this group. In other words, if you consider the null effect of word frequency in the ASD group alongside the Remember/Know by Group interaction, the two findings go hand-in-hand. This leaves open the question of why previous studies have not found a lack of frequency effect in ASD. The word Frequency x Group interaction reported in the current study had a medium effect size Cohen's d = 0.59 and had a power of 0.84 (calculated with G*Power 3, Faul, Erdfelder, Buchner and Lang, 2007). The power reported for the interaction in the current experiment is larger than that reported in Bowler et al. (2000a), which had a small effect size (Cohen's d = 0.13) and power of 0.57, suggesting that previous null findings may have lacked sufficient power[3]. Alternatively, another explanation is that the ASD group may have used other strategies to memorise the words during the study phase (e.g. mnemonic strategies or non-verbal strategies). Nevertheless, both groups made more Remember judgements to low frequency words than to high frequency words suggesting that ASD individuals' Remember responses are qualitatively similar to those of TD individuals. These findings provide an important basis for discussing the ERP findings from Experiment 3.

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[3] **Power comparisons here are based on measured effect sizes, which differ depending on the mean difference and variability between studies. As a result this conclusion should be treated as speculative.**

5.3 Experiment 3

5.3.1 Introduction

One of the earliest observations of memory in children with ASD was that unlike TD children, they fail to use syntactic structure or associative/semantic relations amongst items in word lists to aid subsequent recall (Hermelin & O'Connor, 1970). This observation led to the conclusion that one of the core difficulties in individuals with ASD is to encode information meaningfully. Similar observations have been made for individuals with low functioning ASD (Fyffe & Prior, 1978), and for individuals with high functioning ASD (Bowler et al., 1997) in free recall tasks for related versus unrelated word lists.

Research on memory for the associative relations amongst to be remembered word lists has revealed that perfectly healthy and intelligent participants will make false positives to newly presented test words that are associatively related to studied words. For example, individuals may falsely Remember or Know the word 'sleep' after studying a list of associatively related words such as 'dream', 'bed' and 'rest' (DRM paradigm, Deese, 1959; Roediger & McDermott, 1995, see section 1.4.1). This finding demonstrates the participants' ability to make use of the associative information within the word list. Surprisingly, false (non-presented but associatively related test word) recognition can be more persistent than true recognition (McDermott, 1996), and even when informed about the associative relations, participants cannot prevent these illusions from occurring (Gallo, Roberts & Seamon, 1997). For TD aging individuals, the propensity to become more susceptible to these illusions increases (Schacter, Verfaellie & Anes, 1997).

The notion of a retrieval rather than encoding difficulty in ASD has been proposed by Boucher and Warrington (1976), and has been supported by findings of preserved memory for illusions in ASD. Studies that have investigated illusory memories in ASD have reported similar findings to TD individuals. For example, Bowler et al. (2000b) used the DRM paradigm in a free recall task and recognition memory test and found no evidence of insensitivity to the associative nature of the study lists in individuals with ASD. When presented with a non-studied but associatively related test word, individuals with ASD were just as likely as the TD group to recognise it, a finding that has subsequently been independently replicated (Gaigg and Bowler, 2009; Kamio & Toichi, 2007; Hillier et al., 2007, but see Beversdorf, Smith, Crucian, Anderson & Keillor et al., (2000). Together these findings suggest that ASD individuals are sensitive to the associative relations amongst word lists but are less likely to spontaneously recruit this information to aid subsequent recall.

In their study, Bowler and colleagues (2000b) found that recognition in the ASD group was characterised by fewer episodic Remember judgements and more semantic Know judgements than TD individuals. Furthermore for participants who claimed to Remember a non-presented but associatively related test word, these memories were not void of spatial and temporal contextual information in the form of semantic Know judgements but often as episodic Remember judgments. Bowler and colleagues' findings provide support for the suggestion that during the study phase of the tasks, by virtue of the associative strength of the word lists, the non-presented associated word was consciously activated for both TD and ASD groups, which suggests that both groups engaged in similar encoding processes.

Retrieval processes are thought to contribute towards the false recognition of non-presented, associatively related lure words. Arndt and Hirshman (1998) suggest that the similarity between studied and test items results in false recognition. Semantic false recognition is thought to rely upon global similarity (Yonelinas, 1998), whilst episodic false recognition entails the retrieval of specific information about the studied items, for example the associative, contextual or source information (Curran & Cleary, 2003). Alternatively, false memory may reflect the combined processes of encoding and retrieval. McDermott and Watson (2001) proposed the dual-process 'activation-monitoring' model. They argue that the activation of a non-presented lure word can occur during either encoding or retrieval. In addition to the activation of the non-presented lure word they proposed the importance of a 'monitoring' process, or a strategic, controlled process that enables the rememberer to disentangle prior thought from overt experience. Retrieval related ERPs have been used to study the neural mechanisms that underlie false recognition in TD individuals and are especially insightful for understanding covert recognition memory processes in ASD. This is because true and false stimuli differ in their previous sensory and lexical processing, allowing the comparison of retrieval phase brain activity for stimuli that is uncontaminated by prior encoding processes (i.e., for new items) in the two groups.

Several recent studies have investigated the neural correlates associated with true and false recognition during retrieval. This includes studies using positron emission topography (PET), (Schacter, Reiman, Curran, Yun, Bandy, McDermott & Roediger, 1996), fMRI (Schacter et al., 1997) and ERPs. The mid-frontal Old-New effect and parietal Old-New effect have been measured to investigate whether the semantic or episodic memory systems (respectively) differ between true and false recognition judgements. In one study, Geng, Qi, Li, Fan, Wu et al. (2007) presented participants with lists of to-be-remembered, Chinese two-character words in a DRM illusory memory paradigm. Ninety-six lists were used, each comprising 15 associates arranged in decreasing relatedness. False Targets were the seven highest associates in each of the lists.

ERPs recorded during retrieval revealed waveforms for true and false recognition that were characterised by equal early Old-New effects (300-500 ms), suggesting that although this ERP effect successfully discriminates between correctly identified Old words versus correctly rejected New words (Curran & Friedman, 2004; Nessler & Mecklinger, 2003), it does not discriminate between true and false recognition. A similar pattern has been observed for lures using plurality reversals (Curran, 2000), semantically similar words (Nessler et al., 2001) and mirror-reversed pictures (Curran & Cleary, 2003). The findings from these studies provide converging evidence to suggest that the early mid-frontal Old-New effect is equal for true and false recognition. As discussed in section 1.6, this ERP effect is hypothesised to be associated with 'Know' recognition judgements made on the basis of semantic memory that is void of any contextual detail or information relating to its source.

Conversely, the parietal Old-New effect has been found to differ between true and false recognition, and is more positive for true recognition compared to false recognition, suggesting more active episodic recollection of perceptual details (Geng et al., 2007; Curran & Cleary, 2003; Curran & Friedman, 2004; Curran et al., 2001; Nessler & Mecklinger, 2003; Nessler et al., 2001). The parietal Old-New effect is related to the recollection of specific information, associative information, source recollection and the discrimination between studied words versus non-studied conjunctions (Allan, Wilding & Rugg, 1998; Donaldson & Rugg, 1998; Rubin, Hinton & Wenzel, 1999; Wilding & Rugg, 1996), and when participants judge recognised items as Remembered rather than Known (Düzel et al., 1997; Rugg et al., 1998; Rugg & Curran, 2007). Assuming recollection is more prevalent for hits than false alarms (see Yonelinas, 2001a), these findings are consistent with the association between recollection and the parietal Old-New effect.

The next experiment reported here investigated ERP Old-New effects for memory illusions in ASD using the DRM paradigm. The highest associates of a non-presented target word were chosen as False Targets. Based on the results of Bowler et al. (2000b), it was expected that overall recognition proportions would not differ between the two groups, and that both groups of individuals would be susceptible to false memory illusions. Recognition in the ASD group was expected to show diminished episodic Remember judgements but preserved semantic Know judgements compared to TD individuals. The TD group was expected to show an early mid frontal Old-New effect for Know judgments and a later parietal Old-New effect for remember responses. Enhanced True Target Remember Old-New effects relative to False Target Remember Old-New effects were expected, but no difference was expected between True and False Know Old-New effects. The corresponding ERPs were investigated in both the ASD and the comparison group. Based on the findings from Experiment 1, for True Targets it was expected that the Old-New effect would show topographical differences between the ASD and TD groups from 300-800 ms and following 800 ms be shorter lasting in the ASD group. This

study investigated whether the diminished Old-New effect in ASD stemmed from Remember ERPs, Know ERPs or from both types of judgment.

5.3.2 Method

5.3.2.1 Participants

Fourteen ASD participants, (2 females) and 16 TD participants (2 females) took part in the study and were recruited though a database at City University London. All were right handed and reported normal or corrected to normal vision. Ages ranged from 20.10 to 55.92 years in the TD group and 21.79 to 59.93 years in the ASD group. Individuals in the ASD group all had a clinical diagnosis and a review of their clinical records confirmed that all met DSM-IV- TR (2000) criteria. All ASD participants met criteria for the Autism Spectrum cut off on the ADOS – G and/or the ADI – R. Diagnoses were made by professionals experienced in the field of Autism, data for which was gathered in one-to-one interviews with the participants or their caregivers. The experiment was approved by the ethics committee at City University London.

Participants were individually matched on Verbal IQ and Full-Scale IQ using the WAIS-III-R scales of intelligence to within 7 points. Performance IQ, Age and Gender were matched across groups. The AQ was administered to both the TD and ASD groups to screen the TD group for possible ASD related conditions. Averages for the participants' ages, AQ score, VIQ, PIQ and FIQ are presented in Table 5.3.

	TD (N=16)		ASD (N=14)	
	M	SD	M	SD
Age (years)	36.32	12.26	40.17	14.44
VIQ	112	17	115	11
PIQ	112	16	112	14
FIQ	113	17	115	13
AQ	16	6	35	7

Table 5.3: Mean and standard deviation for Age, AQ and IQ measures (WAIS-III-R). VIQ = Verbal IQ, PIQ = Performance IQ, FIQ = Full-scale IQ for Experiment 3.

5.3.2.2 Stimuli

The stimulus set comprised 24 lists of 15 associatively related words (Roediger & McDermott, 1995). Each list belonged to a 'category' word. The category word along with its 3 highest associates did not figure on the study list but were used in the test lists as False Targets.

Participants studied 6 blocks of 48 words and were asked to memorise the words for a later memory test. At test 16 of the studied words (True Targets) were randomly selected and presented, interspersed with 16 False Targets (the three highest semantic associates of each list plus the category word of each list) and 16 matched new words. Words in each test phase block were presented subsequent to and directly after the study words for each block. New words were matched to the study words on Imagability, Kucera & Francis (1967) written frequency, and number of syllables and taken from the Medical Research Council Psycholinguistic database (http://www.psy.uwa.edu.au/mrcdatabase/uwa_mrc.htm).

As in Experiment 2, the practice trial included a questionnaire (see Appendix 2) that assessed the quality of participants' Remember and Know judgements. The answers to the questionnaire were discussed before the electrode cap was fitted to ensure that participants fully understood the task instructions.

5.3.2.3 Presentation

The experiment took place in a dimly lit and sound attenuated EEG laboratory. Participants sat directly opposite a 15-inch computer screen which presented all stimuli at a viewing distance of 70cm. Minimum and maximum horizontal visual angles were 1.23° and 5.72° respectively. Study phase stimuli were presented every 1.7s (0.5s fixation and 1.2s stimuli presentation) and test phase stimuli every 2.5s (0.5s fixation and 2s stimuli presentation). After each test word was presented participants were asked to make an Old-New recognition judgement and following each recognised word a Remember/Know judgement was requested. Response buttons were counterbalanced across participants.

5.3.2.4 EEG/ERP Acquisition

The scalp ERPs were recorded with 32 Ag/AgCl electrodes with integrated noise subtraction circuits (ActiCAP system) fixed onto an electrode cap according to the International 10-20 System. Electrode impedances were kept below 20kΩ (Kappenman & Luck, 2010). The EEG signal was recorded with a band pass of DC - 100Hz and digitized at a rate of 500Hz. All electrodes had an average online recording reference but were re-referenced offline to a linked mastoid reference to be consistent with the majority of research (Düzel et al., 1997). A further 4 electrodes were fixed to monitor and reject eye blink and eye movement artifacts (electrodes were placed above and below the participant's dominant eye and at the outer canthus of each eye). Eye blinks and movements were detected and corrected using independent components analysis ocular correction transformations (Brain Vision Analyser 2.0.1). Artifacts were rejected using gradient (60µV step per data point) and amplitude (+/-200µV) criteria. The data were filtered using a Zero-Phase Butterworth filter 0.05-20Hz with a 48dB/octave high pass slope.

Following this the data were segmented into epochs lasting 1200 ms (including a 200 ms baseline correction) and averaged according to stimuli type. Trials in which the participant gave incorrect responses (e.g. falsely identified new word or missed True Target) were not included in the average.

5.3.2.5 Data Analysis

The raw True Target and False Target hit rates were corrected by subtracting the proportion of false alarms (i.e., incorrectly indorsed non-associatively related new items) from the proportion of True Target and False Targets respectively. For the electrophysiological results, mean ERP amplitude measures were computed at each scalp electrode using three time-windows: 300-500 ms, 400-800 ms and 800-950 ms encompassing the latency periods of the mid-frontal Old-New effect, the parietal Old-New effect and the diminished Old-New effect reported in Experiment 1. These measurements were performed on the ERP averages for old and new words, for True Targets and False Targets separately.

To reduce Type 1 error as result of multiple comparisons, electrodes were clustered into four regions of interest (following Duzel et al., 1997); anterior (F3/Fz/F4/FC1/FC2), central (C3/Cz/C4/CP1/CP2), parietal (P3/Pz/P4) and occipital (O1/Oz/O2) regions. The magnitude and scalp distribution of Old-New ERP effects between groups were assessed on the ERP difference waveforms. To ensure that topographic comparisons of ERPs were not confounded by differences in the magnitude of the Old-New effect, significant interactions involving Region by experimental, and/or by group factors were further investigated after vector-length normalization of the ERP amplitudes measurements (McCarthy & Wood, 1985).

5.3.3 Results

5.3.3.1 Behavioural Results

Raw and corrected scores for Remember and Know judgements are presented in Table 5.4 and are graphed in Figure 5.4. The raw data were corrected by subtracting the proportion of false alarms from the proportion of hits.

	TD (N=16)		ASD (N=14)		Both Groups (N=30)	
Raw Scores	M	SD	M	SD	M	SD
True Targets						
R	0.48	0.17	0.44	0.21	0.46	0.19
K	0.22	0.15	0.22	0.14	0.22	0.15
R + K	0.69	0.14	0.66	0.19	0.68	0.16
False Targets						
R	0.11	0.09	0.14	0.10	0.12	0.09
K	0.14	0.09	0.15	0.16	0.14	0.13
R + K	0.25	0.14	0.29	0.17	0.26	0.15
False Alarms						
R	0.01	0.02	0.02	0.03	0.01	0.02
K	0.04	0.04	0.05	0.08	0.04	0.06
R + K	0.05	0.05	0.07	0.10	0.05	0.07
Corrected Scores						
True Targets						
R	0.47	0.18	0.42	0.22	0.45	0.19
K	0.18	0.15	0.17	0.09	0.17	0.13
R + K	0.65	0.16	0.59	0.18	0.62	0.17
False Targets						
R	0.10	0.09	0.12	0.10	0.11	0.09
K	0.10	0.08	0.10	0.10	0.10	0.09
R + K	0.21	0.13	0.22	0.12	0.21	0.12

Table 5.4: Mean and standard deviation of recognition accuracy scores (proportions) for True Targets and False Targets for TD and ASD groups in Experiment 3. R = Remember, K = Know.

The false alarm data are considered first, and then the main results in terms of corrected recognition scores[4]. ANOVA confirmed that that there was no significant difference between groups in the number of New words correctly rejected ($F_{(1, 28)} = 0.66$ p = *n.s.*). Following this, the main results in terms of corrected recognition scores are considered.

The corrected data were analysed using a 2 (True Target/ False Target) x 2 (Remember/Know) x 2 (Group) mixed repeated measures ANOVA. There was no difference in the proportion of words recognised overall between groups (main effect of Group was not

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[4] Corrected scores are calculated using the formula correct Hits-FA. Thus, corrected data are not independent of Hits / False Alarm data and were analysed using a separate ANOVA.

significant F (1, 28) = 0.18, p = *n.s.*). There was also no interaction between True Target/ False Target and Group (F (1, 28) = 1.60, p = *n.s.*) showing that True Target and False Target recognition was equivalent between groups. There was a main effect of True Target/ False Target where both groups recognised more True Targets than False Targets (F (1, 28) =191.57, p< .01). There was also a main effect of Remember/Know where both groups of participants gave more Remember judgements than Know judgements (F (1, 28) = 17.60, p< .01). Finally, there was a True Target/False Target by Remember/Know interaction (F (1, 28) = 27.10, p< .01) where True Targets were more often Remembered than Known (F(1, 28) = 25.78, p< .01), but for False Targets there was no significant difference in Remember and Know rates (F(1, 28) = 0.16, p = *n.s.*). The Remember/Know x Group interaction for True Targets did not reach significance (F (1, 28) = 0.09, p = *n.s.*).
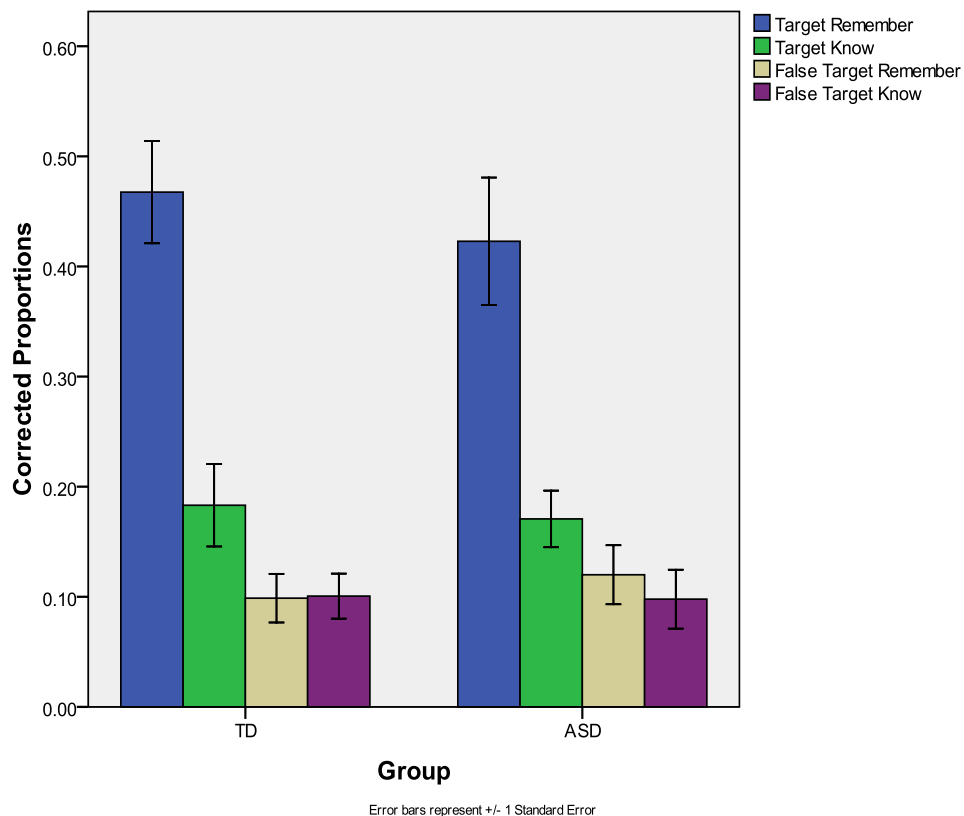
Figure 5.4: Mean proportions of Remembered and Known, True and False Target words recognised by TD and ASD groups for Experiment 3.

5.3.3.2 ERP Results

The analyses of the electrophysiological data were conducted to investigate True and False Target Old-New potential differences between ASD and TD groups. The mean number of artifact-free trials with correct answers included in the ERP averages for the TD group, R = 69, K = 31, false R = 40, false K = 33, New = 90. For the ASD group, R = 49, K = 28, false R = 35, false K = 27, New = 86. Independent samples t-tests revealed that artefact free trial numbers for True Remember ($t(28) = 1.84$, p >.05), True Know $t(28) = 0.48$, p >.05, False Remember ($t(28) = 0.59$, p >.05), False Know ($t(28) = 0.78$, p >.05) or New ($t(28) = 1.87$, p >.05) word conditions did not significantly differ between groups.

Description of ERP waveforms

The ERP waveforms for True recognition to Old and New words are shown at all sixteen electrode locations in Figure 5.5, and ERP waveforms for false recognition are presented in Figure 5.6. Both groups displayed ERP amplitude differences between Old and New words, with Old words eliciting greater positive ERP voltages than New words post 300 ms. Figure 5.7 displays the 2D scalp distributions of the Old-New effect from 300-950 ms for both groups. The Old-New effect was longer lasting in the TD group compared to the ASD group. Figure 5.8 displays the 2D scalp distributions of True and False, Remember and Know Old-New mean ERP amplitude differences in the 300-500 ms, 400-800 ms and 800-950 ms time windows for TD and ASD groups.
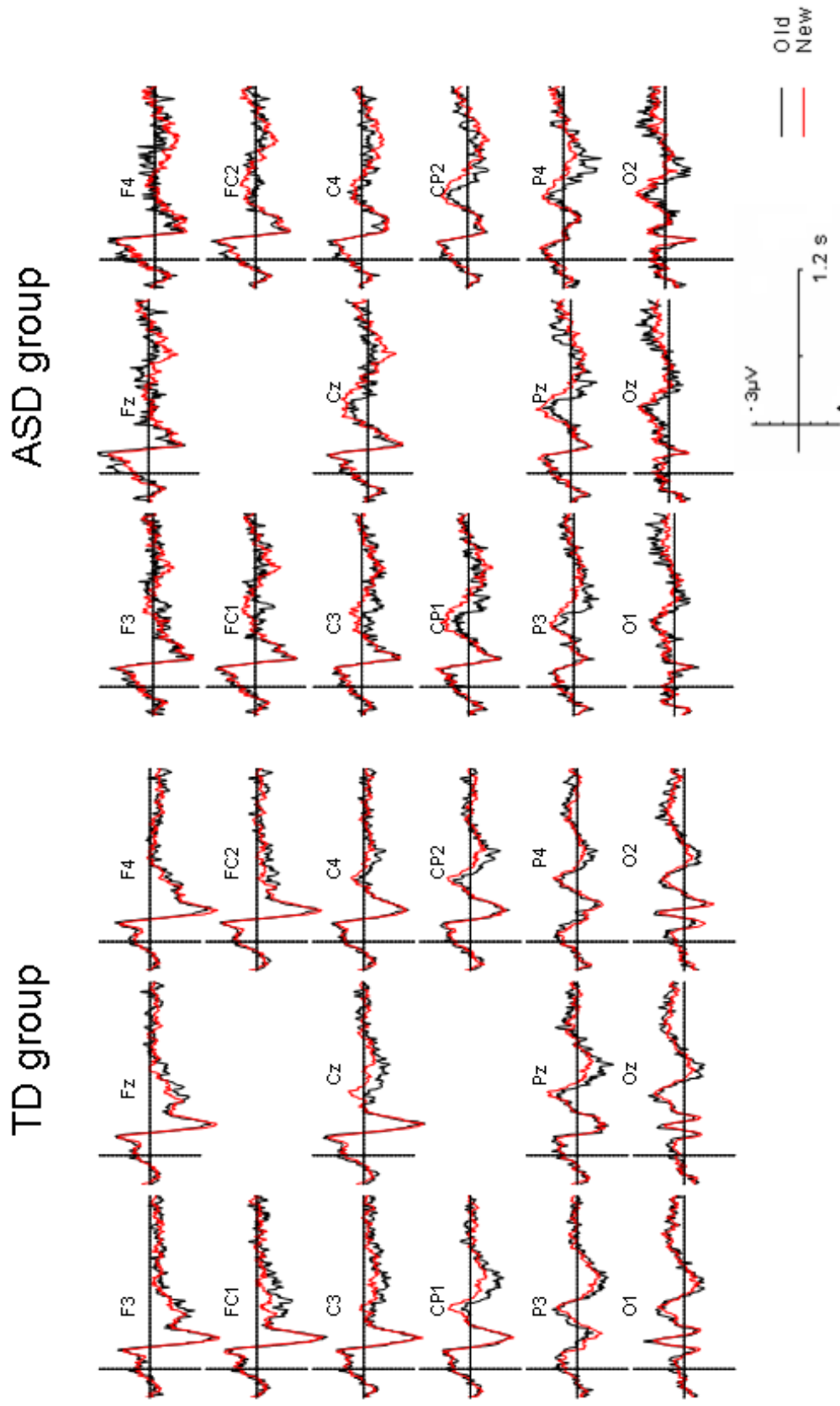
Figure 5.5: True ERP Old-New effects for TD (N=16) and ASD (N=14) groups for Experiment 3 shown at all sixteen electrodes. Old word ERPs are presented in black and New word ERPs in Red.
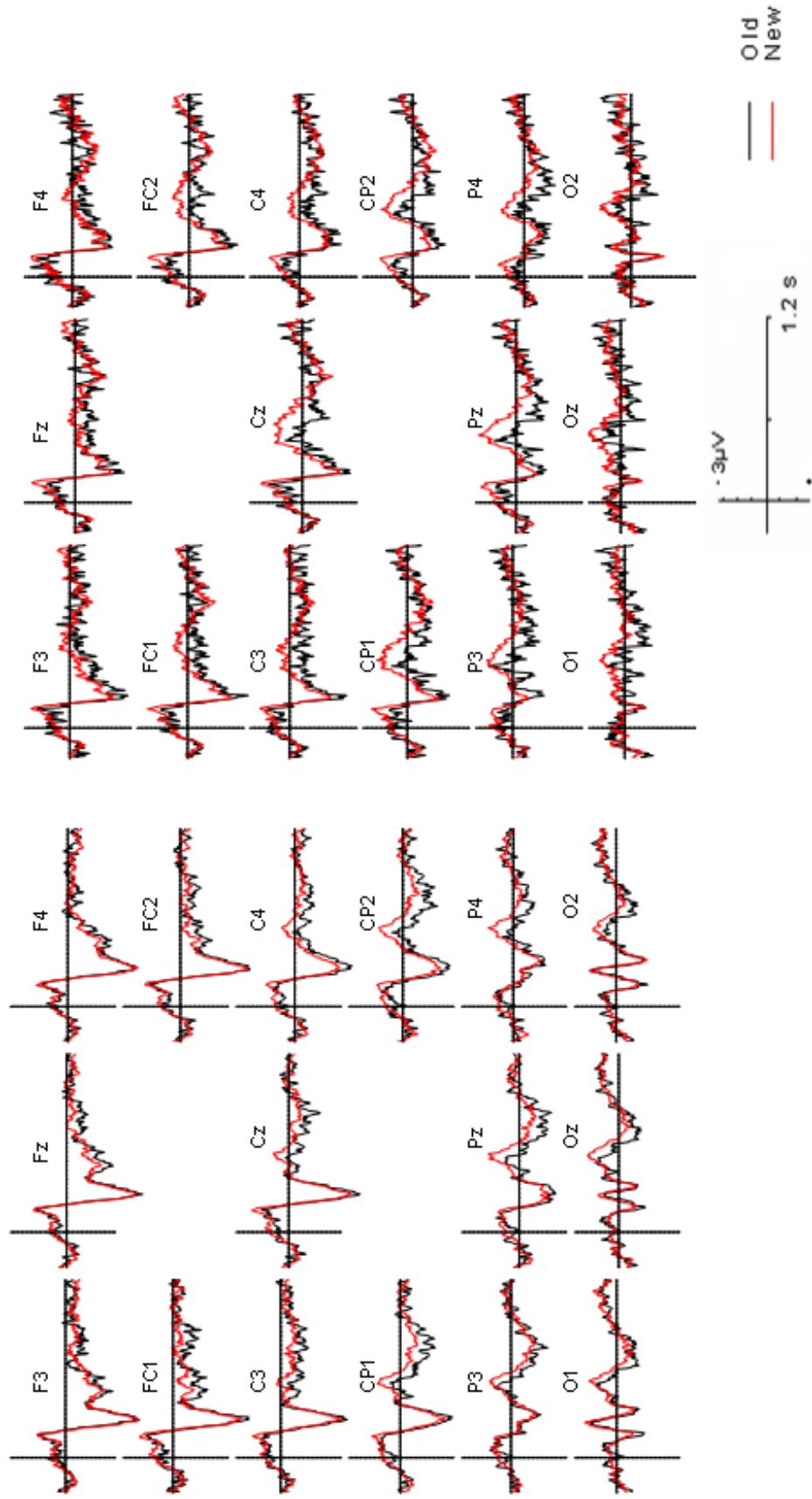
Figure 5.6: False ERP Old-New effects for TD (N=16) and ASD (N=14) groups for Experiment 3 shown at all sixteen electrodes. Old word ERPs are presented in black and New word ERPs in Red.

Figure 5.7: 2D scalp distributions of Old-New ERP effect (Old minus New words) in the 300-500 ms, 400-800 ms and 800-950 ms time windows for TD (N = 16) and ASD (N = 14) groups for Experiment 3.
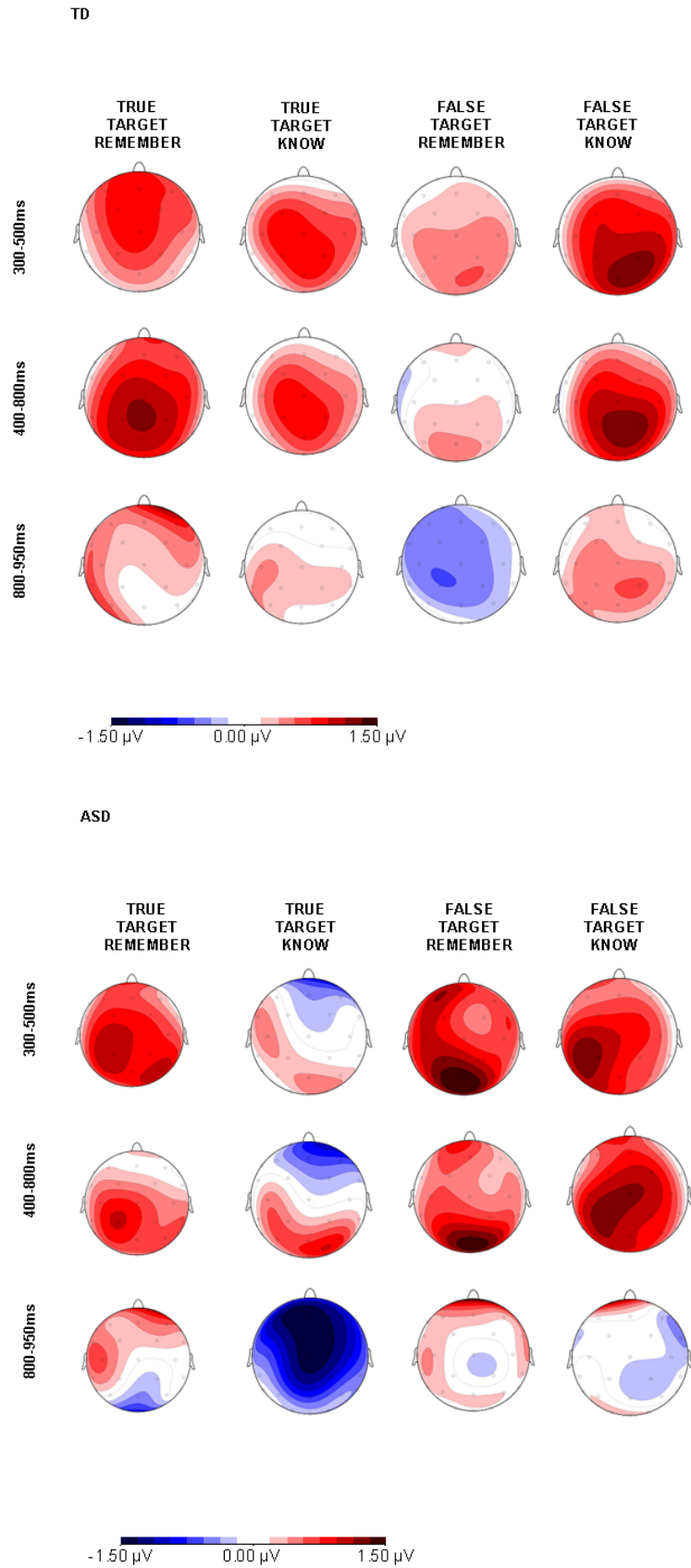
Figure 5.8: 2D scalp distributions of True and False, Remember and Know Old-New mean ERP amplitude differences (Old minus New words) in the 300-500 ms, 400-800 ms and 800-950 ms time windows for TD (N = 16) and ASD (N = 14) groups for Experiment 3.

5.3.3.3 True Target Remember and Know Old minus New amplitude effects

The Remember Old-New ERP effect for True Targets in TD participants was characterised by two spatially and temporally different ERP effects (see Figure 5.8). A mid-frontally distributed Old-New ERP effect was observed in the 300-500 ms time-window and a parietally focussed Old-New ERP effect in the 400-800 ms time-window, which is consistent with the Old-New ERP effects reported in previous studies (see Rugg & Curran, 2007). Remember Old-New effects for True targets were positive from 800-950 ms and showed right anterior positivity (consistent with the Late Frontal Effect) coupled with a left parietal positivity. The Remember Old-New effect for True Targets in the ASD group showed a parietal focus for both time windows. From 800-950 ms the Remember Old-New effect for True targets showed right anterior positivity but was less widespread than in the TD group.

The Know Old-New ERP effect for True Targets in TD participants was characterised by a large central-focussed Old-New effect from 300-500 ms, which continued from 400-800 ms (consistent with previous findings, e.g., Curran, 2000). For the ASD group the Know Old-New effect showed a parietal focus from 400-800 ms. From 800-950 ms there was a large anterior negativity in the ASD group, which was not present for the TD group.

5.3.3.4 False Target Remember and Know Old minus New amplitude effects

The False Target Remember Old-New effect in the TD group was characterised by parietal focus positivity from 300-500 ms and 400-800 ms. The False Target Remember Old-New effect was negative for TD individuals from 800-950 ms. For TD individuals False Target Remember Old-New effects appeared smaller than True target Old-New effects (consistent with previous findings, Curran & Friedman, 2004). For ASD individuals, the False Target Remember Old-New effect showed a parietal focus and by 800 ms the effect was widely reduced (a similar topography as the TD group). False target Remember Old-New effects for ASD individuals appeared larger than for the TD group.

False Target Know Old-New effects in the TD group showed central-parietal positivity from 300-500 ms, which was also present from 400-800 ms and 800-950 ms. For TD individuals, True and False Target Know Old-New effects shared a similar topography. For the ASD group False Target Know Old-New effects showed central-parietal focus from 300-500 ms which continued from 400-800 ms. By 800 ms the False Target Know Old-New effect had ended in the ASD group.

5.3.3.5 ERP Analysis

The effects described above were statistically assessed using repeated measures ANOVAs with 'Group' as between-subjects factor and 'Latency' (300-500 ms/400-800 ms/800-950 ms), 'True/False', 'Remember/Know' and 'Region' (anterior /central /parietal /occipital) as within-subjects factors. Greenhouse-Geisser corrections are reported wherever assumptions of sphericity are violated. In order to compare the magnitude of True, False, Remember and Know ERPs in one analysis and for simplicity, Old-New difference ERPs were calculated. This was done by subtracting the amplitude of correctly rejected New words from Old words in each stimulus category, Latency interval and Region. As difference values were calculated prior to statistical analysis, significant main effects of Region and/or Latency are a measure of differences in the Old-New effect. The mean and standard deviation amplitudes for each region of interest at each time window can be seen in Table 5.5.

				TD (N=16)		ASD (N=14)	
				M	SD	M	SD
300-500ms	True	Remember	Anterior	0.73	0.85	0.11	1.12
			Central	0.57	0.79	0.68	0.92
			Parietal	0.30	0.69	0.66	1.21
			Occipital	-0.00	1.01	0.40	0.88
		Know	Anterior	0.23	1.21	-0.21	1.42
			Central	0.52	1.02	0.22	1.28
			Parietal	-0.06	0.89	0.32	1.23
			Occipital	-0.15	0.87	0.27	1.34
	False	Remember	Anterior	0.19	0.98	0.74	0.94
			Central	0.33	0.94	1.00	0.50
			Parietal	0.32	1.04	1.38	0.88
			Occipital	0.14	0.98	1.03	1.02
		Know	Anterior	0.89	1.54	0.63	0.95
			Central	1.24	1.56	1.07	1.01
			Parietal	1.30	1.48	0.92	1.05
			Occipital	0.83	1.09	0.80	1.37
400-800ms	True	Remember	Anterior	0.66	1.20	0.43	1.45
			Central	0.91	1.02	0.72	1.05
			Parietal	0.82	0.98	0.88	1.31
			Occipital	0.48	1.04	0.44	0.89
		Know	Anterior	0.22	1.39	-0.43	1.46
			Central	0.33	1.08	0.19	0.92
			Parietal	0.10	1.08	0.70	1.30
			Occipital	0.02	0.94	0.27	1.01
	False	Remember	Anterior	0.01	1.31	0.27	1.11
			Central	0.09	1.06	0.51	0.71
			Parietal	0.21	1.02	1.18	1.02
			Occipital	0.13	1.02	0.94	1.10
		Know	Anterior	0.73	0.99	0.81	1.88
			Central	1.29	1.26	1.14	1.73

				TD		ASD	
			Parietal	1.12	1.13	1.03	1.31
			Occipital	0.83	1.24	0.77	1.33
800-950ms	True	Remember	Anterior	0.58	1.48	-0.01	1.33
			Central	0.36	1.18	-0.25	0.96
			Parietal	0.23	1.09	-0.33	1.05
			Occipital	0.05	0.95	-0.82	1.02
		Know	Anterior	-0.31	1.71	-1.40	2.66
			Central	-0.18	1.23	-1.14	1.68
			Parietal	-0.21	1.52	-0.41	1.92
			Occipital	-0.29	1.59	-0.31	1.64
	False	Remember	Anterior	-0.41	1.88	-0.26	2.03
			Central	-0.48	1.25	-0.35	1.62
			Parietal	-0.38	1.03	0.15	1.11
			Occipital	-0.18	1.34	-0.05	1.45
		Know	Anterior	0.38	1.09	-0.44	2.12
			Central	0.80	1.12	-0.38	1.40
			Parietal	0.58	0.95	-0.10	1.68

Table 5.5 Means and standard deviations for the amplitude differences at each region of interest in the TD and ASD groups for Experiment 3. Amplitude measures are in µV.

For the following analysis (and consistently for all studies reported in this thesis) all statistically significant main effects and interactions are reported. Higher-order interactions are reported following all statistically significant lower-order interactions and main effects.

There was a significant Latency x Group interaction ($F_{(2, 56)} = 3.45$, $p<.05$), which replicated the findings of Experiment 1 of shorter lasting Old-New effects in the ASD group (see Figure 5.7). The Old-New amplitude difference for TD individuals was positive for all three time windows but was negative for ASD individuals from 800-950 ms (mean voltage amplitude difference from 300-500 ms; TD = 0.46µV, ASD = 0.63 µV, 400-800 ms; TD = 0.50 µV, ASD = 0.62 µV, and 800-950 ms; TD = 0.05 µV, ASD = -0.35 µV). Separate analyses for each latency interval revealed that the Old-New effect did not differ between groups from 300-500 ms ($F_{(1, 28)} = 0.62$, $p = .44$, *n.s.*), or from 400-800 ms ($F_{(1, 28)} = 0.27$, $p = .61$, *n.s.*) but was marginal from 800-950 ms ($F_{(1, 28)} = 3.00$, $p = .09$) suggesting that the significant Latency x Group interaction reported above stemmed from a positive Old-New effect in the TD group and negative Old-New effect in the ASD group from 800-950 ms.

The main effect of True/ False was significant ($F_{(1, 28)} = 4.43$, $p<.05$) and was qualified by a significant True/ False x Remember/ Know interaction ($F_{(1, 28)} = 10.08$, $p <.01$). The interaction showed that Remember True Target and False Target Old-New effects were comparable ($F_{(1, 28)} = 0.30$, $p = .59$), but that False Target Know Old-New effects were more positive than Target Know Old-New effects ($F_{(1, 28)} = 9.07$, $p <.01$).

The Latency x Remember/Know x Region interaction was significant ($F_{(3.17, 88.70)} =$

5.55, p <.01) and differed between groups (Latency x Remember/Know x Region x Group interaction, F (3.17, 88.70) = 5.49, p <.01). As the topography of the Remember/Know Old-New effects differed across Latency interval, repeated measures ANOVAs were run for each time window. From 300-500 ms and 400-800 ms the Remember/Know x Region interaction was not significant, and did not differ between groups. From 800-950 ms the Remember/Know x Region interaction was significant (F (1.95, 54.86) = 4.12, p <.05), and was qualified by a significant Remember/Know x Region x Group interaction (F (1.95, 54.86) = 4.23, p <.05). Further analysis revealed that the Remember/Know x Region interaction was not significant for TD individuals (F (1.80, 26.99) = 0.82, p = 0.44, *n.s.*) but was significant for the ASD group (F (2.11, 27.39) = 8.89, p<.01). The Remember/Know x Region interaction in the ASD group was qualified by significantly more negative Know Old-New effects than Remember Old-New effects at anterior regions (F (1, 13) = 5.95, p<.05, K = -0.92 µV, R = -0.13 µV) but no significant difference at central (F (1, 13) = 1.56, p = .23, *n.s.*), parietal (F (1, 13) = 0.25, p = .63, *n.s.*) or occipital regions (F (1, 13) = 2.21, p = .16, *n.s.*). Overall these results demonstrate a late anterior negativity for Know judgements in the ASD group from 800-950 ms.

To ensure that topographic comparisons of the ERP data were not confounded by differences in the magnitude of the Old-New effect, significant interactions involving Region by True/False, Latency and/or by Group were further investigated after RMS-z normalization of the ERP amplitudes measurements (McCarthy & Wood, 1985). The analysis was repeated with the normalised data and revealed that the Latency x Remember/Know x Region x Group interaction remained marginally significant once sphericity violations were controlled for (F (3.72, 104.91) = 2.42, p = .057), and as previously reported, this was due to a significant negativity in the Know Old-New difference and not for Remember judgements at anterior regions from 800-950 ms for ASD individuals only (F (1, 13) = 5.57, p<.05).

5.3.4 Discussion

The results from Experiment 3 confirmed that overall recognition performance did not differ between groups, replicating previous findings of preserved recognition memory in ASD. Both groups were susceptible to false memories, that is, they both recognised an equal proportion of non-presented but associatively related False Target words. It was predicted that True Target Remember judgements would be quantitatively diminished in ASD with spared Know judgements (as in Experiment 2 and previous studies in ASD, see Bowler et al., 2000a, b, 2007) but the interaction did not reach significance. However, as can be seen in Figure 5.4, there was a slight trend for diminished episodic Remember judgements in the ASD group for True Targets.

The ERP data confirm existing findings of Old-New effects in TD individuals and replicate

the finding of diminished Old-New effects in ASD post 800 ms as observed in Experiment 1 (see Figure 5.2) in an independent sample of ASD individuals. The diminished Old-New effect in ASD stemmed from a late occurring anterior negativity for Know judgements in the ASD group from 800-950 ms which was absent in the TD group. These data suggest that a distinct patterning of neural differences underlies semantic recognition memory performance in ASD.

These findings add to behavioural literature that suggests episodic Remember judgements in ASD are qualitatively similar to those of TD individuals (Bowler et al., 2007) as both groups showed a parietal focus for Remember judgements from 400-800 ms (in line with current literature, Rugg & Curran, 2007). This suggests that similar neural generators were driving episodic memory in both groups. Additionally Remember Old-New effects showed no group differences from 300-800 ms suggesting that episodic judgements in ASD are qualitatively similar to TD individuals. Qualitative descriptions of Remembering and were, in addition, indistinguishable between groups (see Appendix 1 and Bowler et al., 2000a).

From 800-950 ms group differences were observed for Know Old-New effects which were characterised by a late anterior negativity in the ASD group. This was not present for the TD group. This provides evidence to suggest that semantic Know judgements in the ASD group are mediated by late anterior neural generators. Furthermore, the findings imply that there are qualitative differences in the operation of semantic Know judgements between groups. The negativity may be associated with strategies engaged during semantic recognition in the ASD group to offset diminished episodic memory judgements (Bowler et al., 2000a, b, 2007, see Experiments 2 and 5 in this thesis). These strategies may manifest in typical behavioural semantic memory performance for individuals with ASD.

When participants make a Know judgement, by definition, they are consciously aware of an experience they cannot Remember. Words such as those used in this experiment are frequently encountered, and in the absence of remembering the stimuli, it may be more difficult to attribute the memory to the study phase. On the other hand, participants may attribute awareness of other recent encounters of the word to the study phase of the experiment. Know judgements are also based on much less subjective information than Remember judgements. Remembering over Knowing requires the recollection of rich information concerning the time in which a particular event was encountered (Tulving 2002). By virtue of this, Know judgements are likely to include more guess responses compared to Remember responses. Perhaps one way to reduce this variability and better understand the greater anterior negativity for Know responses would be to include a guess response, i.e., having response options of 'Remember/Know/Guess'. Over successive blocks of trials (and as a large sample of test word stimuli were employed) increased guess responses within Know judgements may also account

for the lack of Remember/Know x Group interaction here.

It was predicted that Remember Old-New effects would be larger for True Targets than for False Targets due to the enhanced episodic recollection of perceptual details from the study phase, however no difference was observed: Target and False target Remember Old-New effects were comparable for both the TD and ASD groups suggesting that both groups' phenomenological Remember experiences for True and False targets were similar. This may have been because of the strong associative links between the True Target and False Target stimuli used in the study, which (by virtue of their associative strength) may have activated a representation of the non-presented False Target word. Comparable Old-New effects for True and False Target Remember judgements have also been previously reported in studies using the same stimuli as those used here (Düzel et al., 1997).

To summarise, overall behavioural recognition did not differ between groups for the True or False target stimuli demonstrating that both groups were susceptible to illusory false memories. It was expected that the ASD group would show diminished episodic memory but this finding was not replicated here. It is possible that increased guesses within the responses for Know judgements could account for this result, as participants may have attributed other recent encounters with word stimuli with noetic awareness. Stimuli such as non-nameable pictures or stimuli that are not likely to have been encountered previously could be used in a further study to test this hypothesis. Moreover, some of the participants in this experiment may have been aware of the hypotheses of the study (seven Remember/Know studies have been conducted in the Autism Research Group laboratory since 2000: Bowler et al., 2000a, b, 2007; Experiment 2; Experiment 3). Furthermore, 8 out of the 14 ASD participants who took part in Experiment 3 had participated in Experiment 2. The current study replicated the findings from Experiment 1 of shorter lasting word recognition Old-New effects in ASD (ending approximately 800 ms and persisting until 950 ms in the TD group). Know judgements showed central-parietal Old-New effect from 300-500 ms and Remember judgements showed the expected parietal Old-New effect from 400-800 ms for both groups across both True and False targets. Know Old-New effects in the ASD group were characterised by a late large anterior negativity (800-950 ms). Although topographical Old-New group differences in Experiment 1 occurred during an earlier time window than differences observed in Know Old-New effects in Experiment 3, both studies converge on the suggestion that differing functional neurophysiological processes operate within semantic Know judgments in ASD and that it is the semantic, rather than episodic memory system that operates atypically in this population.

The motivation of this study was based on the findings of diminished episodic and preserved semantic memory in ASD during previous behavioural tests of recognition. The

present findings demonstrate observable between-group ERP differences within the semantic memory system, an observation that supports accounts of diminished behavioural episodic memory and reduced processing of contextual information. However, the conclusion that individuals with ASD show differing ERP Old-New effects is constrained because these studies have exclusively relied upon stimuli that involve verbal processing. Remembering and Knowing were measured using stimuli that were rich in context and meaning. For example, participants were asked to memorise lists of words (as in Experiments 1 to 3) which they are likely to have encountered prior to the study phase. The result is that these words are not only nameable, but they also hold pre-existing contextual information. Remember and Know judgements may, as a consequence, be influenced by this pre-existing contextual baggage, and furthermore, groups may differ in their ability to use these labels and context to support recognition. Therefore the next experiment to be reported here considered Remember and Know ERP Old-New effects for novel and non-nameable images.

Chapter 6 : ERP OLD-NEW EFFECTS FOR NON-NAMEABLE AND NOVEL KALEIDOSCOPE IMAGES

6.1 Experiment 4

6.1.1 Introduction

Individuals with ASD have a unique profile of perceptual and cognitive ability, where superior performance for adults with ASD is observed in the processing of local featural information (for example the Block Design Task, see Stewart, Watson, Allcock & Yaqoob, 2009), and enhanced ability for children with ASD to discriminate features (Shah & Frith, 1983, 1993). Visual illusions have been especially insightful for this area of research as they require the individuals to focus on the detail of visual stimuli and somewhat exclude the wider context. They are assumed to work because TD individuals 'see' objects differently depending on their context. In the Muller-Lyer illusion, for example judgements about the relative length of two horizontal lines is affected by inward or outward pointing arrow heads, which place the lines in context. Similarly in the Titchner Circles illusion the size of surrounding circles biases the perceived size of a central circle (see Figure 6.1 for examples, reproduced from Happé, 1996). Happé (1996) argued that as ASD individuals focus to some extent only on details, they should not be as susceptible to visual illusions as TD individuals. Happé presented the Titchner Circles and the Muller-Lyer illusions to children and adolescents with and without ASD and individuals with intellectual disabilities. Results showed that ASD individuals succumbed less often to visual illusions than comparative participants although the effect was not as great with the Muller-Lyer illusion as the Titchner Circles. She concluded that individuals with ASD were less affected by context in the Titchner Circles visual illusion and explains the weakened effect in the Muller-Lyer illusion by its context being connected to the line to be judged which makes the 'context' part of the local 'detail' to be processed. These studies suggest that individuals with ASD have difficulties defining stimuli with relation to context.
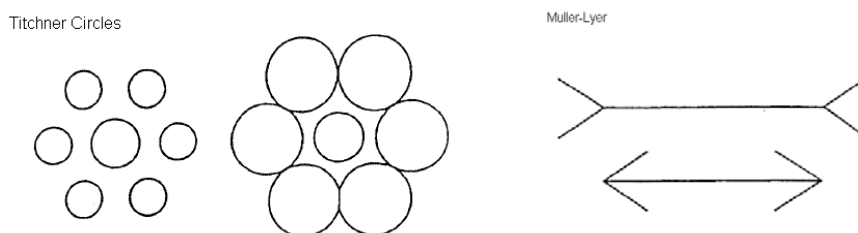
Figure 6.1: Examples of the Titchner Circles and Muller-Lyer Illusions.

The difficulties experienced by ASD individuals with visual illusions are found not only at a visual-perceptual level but also with conceptual processes, for example in language. This may account for the differences observed in the recognition Old-New effects for words in Experiments 1 and 3. It was shown in Chapter 1 that individuals with ASD demonstrate some impairment in the ability to use context to support memory in the recall of semantically associated words (Hermelin & O'Connor, 1967; Tager-Flusberg, 1991; Bowler et al., 1997). Frith and Snowling (1983) and Hermelin and O'Connor (1967) have demonstrated in samples of children with ASD, that providing general context information in the form of sentences, does not improve performance on tasks which require individuals to disambiguate homographs, or, recall. Homographs are words that have the same spelling, but are pronounced differently, the meaning for which is usually determined by the context they written, an example being 'Lead', as in 'metal lead' or 'dog lead' (Bowler, 2007). Snowling and Frith (1986) concluded that autistic individuals less often use the contextual information to determine the pronunciation of the homographs[5]. Happé (1997) furthered this research by conducting a study testing children with or without ASD, using sentences where the homograph occurred before or after the main context of the sentence. She postulated individuals with ASD would not be able to discriminate between the homographs in context if they had not been prompted with different pronunciations of the homographs beforehand. Results showed that ASD individuals used context to discriminate homographs less often than the comparison group, even when context was given before the homograph. This difficulty is thought to demonstrate impairments with integrating information within its context for individuals with ASD because of the difficulties these individuals experience in forming meaningful connections (Happé, 2000), (see Chapter 1).

There is some ERP evidence to suggest that individuals with ASD experience specific deficits with the processing of verbal semantic representations. This is relevant to the ERP differences observed in Experiments 1 & 3, because, as noted in section 1.3, early Old-New ERP effects temporally coincide with the N400, which is associated with semantic processing, and there is evidence of atypicalities in this ERP component in ASD. In a study by McCleery, Ceponiene, Burner, Townsend, Kinnear and Schreibman (2009), for example, verbal and non-verbal semantic processing N400 effects were measured in children with ASD using semantically incongruent versus congruent picture-word and picture-environmental sound pairs. The results demonstrated the TD children's ability to detect semantic incongruence in the form of an N400 modulation for both picture-word and picture-environmental sound conditions. Contrastingly, the

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[5] The inability to differentiate between homographs was also commonly associated with low mental age and was present amongst the ASD individuals and the comparison groups, indicating this difficulty is not specific to individuals with ASD.

ASD group demonstrated typical N400 effects in the environmental sound condition but not for word conditions. Findings of reduced N400 effects in response to verbal semantic incongruence in ASD have also been reported in other ERP studies (see Ring, Sharma, Wheelwright & Barett, 2007; Strandburg, Marsh, Brown, Asarnow, Guthrie & Higa, 1993; Pijnacker, Guerts, van Lambalgen, Buitelaar & Hagoort, 2010; Dunn, Vaughan, Kreuzer & Kurtzberg, 1999).

Strandburg et al. (1993) also demonstrate that reduced N400 amplitudes associated with word pairs do not appear on non-verbal tasks in ASD. In their study, 3 tasks were administered to participants; the Continuous Performance Task (CPT), the span of apprehension task (SPAN) and the Idiom Recognition Task (IRT). The CPT is a presentation of successive trials of an ongoing train of numbers, and requires a response from participants whenever a number repeats on successive trials. The SPAN involves a presentation of brief 12 letter arrays and requires participants to identify which out of two target letters is presented. Therefore the CPT and SPAN are both non-linguistic and complex information processing tasks. A third task developed by Strandburg and colleagues was the IRT, which was used to measure difficulties individuals experience with comprehending non-literal statements. During this task participants were presented with word pairs which were either literally or idiomatically meaningful or nonsensical, and participants were asked to judge whether these word pairs were meaningful or not. The results demonstrated reduced N400 amplitudes to idioms only in the ASD group, whilst amplitude differences were not observed during the CPT or SPAN tasks. The authors concluded that deficits are particularly apparent in the processing of language in ASD.

The findings just described demonstrate that ERP abnormalities in ASD are more prevalent during verbal than non-verbal tasks. However, they do not address memory-related issues such as the recognition Old-New effect. More specifically, they do not address whether reduced Old-New effects in ASD are specific to linguistic or language-related aspects of the studied stimuli. As the studies reported earlier on in this thesis are predominantly verbal tasks, it is important to consider non-nameable stimuli and stimuli that are unlikely to have been encountered by participants prior to the study phase to clarify these findings further.

One way to minimise participants' pre-experimental experience with stimuli would be to use faces. These are unlikely to have been encountered previously and lack pre-experimental contextual detail. They also permit extremely ecologically valid examples of autonoetic and noetic conscious awareness. For example, the 'butcher-on-the-bus' phenomenon (Yovel & Paller, 2004) can be recreated several times. The butcher-on-the-bus phenomenon refers to the awareness of seeing someone you know, but being unable to recall the experience or circumstance in which you first encountered them (noetic awareness). In comparison, autonoetic awareness entails the availability of information and a recollection that the familiar face is (in the

example above) your butcher on the bus. In one study, Yovel and Paller (2004) presented pictures of faces and simultaneous descriptions of occupations, which participants were asked to memorise for a later memory test. A Remember response entailed the successful recollection of the face-occupation association, whilst a Know response was characterised by successful recognition of the face in the absence of a successful occupation association. Although this provides robust measures of Remember and Know judgements in TD individuals, face stimuli may not provide bias-free measures of these judgments in ASD considering the face processing difficulties and proposed difficulties with understanding facial expression in this population (Behrmann, Thomas & Humphreys, 2006; Humphreys, Minshew, Leonard & Behrmann, 2007). Therefore the present experiment necessitates the use of another class of stimuli.

Given evidence of visual-spatial proficiency in ASD (Stewart et al., 2009; Shah & Frith 1983, 1993), novel, meaningless and non-nameable kaleidoscope images were used for this experiment. As the stimuli were new to the participants, Know judgements were restricted to experiences of noetic awareness confined to the experimental study phase. With the large data set of stimuli used in this EEG task, the sequential (Old/New then Remember/Know) response would have resulted in a very time consuming testing session (over three hours per participant). Experiment 4 eliminated the Old/New response and replaced this with a 'Remember/Know/New' response meaning that a larger sample of images could be used with a higher signal-to-noise ratio. Experiment 4 investigated whether diminished recognition Old-New effects in ASD and the late activity observed for semantic Know judgements in Experiment 3 were specific to linguistic or language related stimuli. Experiment 4 investigated this using non-nameable and novel kaleidoscope images.

6.1.2 Method

6.1.2.1 Participants

Twelve ASD participants (3 females) and 12 TD participants (1 female) took part in the experiment. Participants were recruited through a database at City University London. All participants were right handed and reported normal or corrected to normal vision. Age ranged from 23.59 years to 55.92 years in the TD participants and 24.98 years and 55.28 years in the ASD participants. The ASD group all had a clinical diagnosis and a review of their clinical records confirmed that all met DSM-IV- TR (2000) criteria. All ASD participants met criteria for the Autism Spectrum cut off on the ADOS – G and/or the ADI – R. Diagnoses were made by professionals experienced in the field of Autism, data for which was gathered in one-to-one interviews with the participants or their caregivers. Participants were individually matched for Verbal and Full-scale IQ using the WAIS-III-R scales of intelligence to within 7 points, and group matched for Age and PIQ. Averages for the participants AQ, Age, VIQ, PIQ and FIQ for both groups are presented in

Table 6.1. Participants were paid standard university fees for their time and reimbursed travel costs. The experiment was approved by the ethics committee at City University London.

	TD (N =12)			ASD (N =12)	
	M	SD		M	SD
Age (years)	40.13	11.07		40.03	11.41
VIQ	112	19		110	14
PIQ	105	18		112	16
FIQ	110	20		112	15
AQ	16	6		34	9

Table 6.1 : Mean and standard deviation for Age, AQ and IQ measures (WAIS-III-R). VIQ = Verbal IQ, PIQ = Performance IQ, FIQ = Full-scale IQ for Experiment 4.

6.1.2.2 Stimuli

The experiment stimuli comprised 800 kaleidoscope images (the same as those used by Voss & Paller, 2009), created by overlaying three opaque hexagons each with three rounds of distortion using a computerised programme. Each hexagon used a randomly selected colour. The distortion, as described by Voss and Paller (2009), was accomplished by bisecting each side of an image and deflecting each half at a randomly selected angle from the line tangential to the centre of the bisected side. Images were presented at the centre of a computer screen within a square that measured 300 x 300 pixels (85 x 85 millimetres). Examples of stimuli can be seen in Figure 6. 2. Participants sat with their eyes at a distance of 90cm from a 15 inch computer screen which resulted in a visual angle of 10.7°.
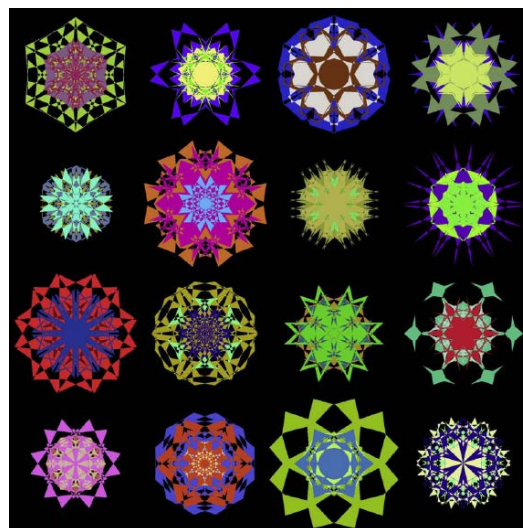
Figure 6.2: Examples of kaleidoscope images used for Experiment 4 (taken from Voss and Paller, 2009).

6.1.2.3 Presentation

Prior to testing, participants were given instructions and asked to complete a practice block consisting of 10 trials. Remember/Know instructions were the same as those in Experiment 2. After the practice, participants were asked to give examples of Remember and Know judgements which were assessed by the experimenter and with the same questionnaire as used for Experiment 3 (see Appendix 2) to make sure the instructions had been understood. Once the practice block was complete the electrode cap was fitted onto the participant.

The experiment took place in a dimly lit and sound attenuated EEG laboratory. There were 40 blocks of images in the experiment; each block presented 10 novel images for the study phase and during each test phase, the 10 studied images were presented with 10 new images. The study images were presented at central fixation for 3.5 s, followed by a 2 s central fixation point. Participants were instructed to memorise each image for a later memory test. Each study phase was directly followed by a test phase. During the test phase, images were presented following a 1.5 s central fixation point and remained on screen for 3 s. After this, participants were asked to discriminate Old from New images by reporting the subjective experience of their judgement (Remember/ Know/ New judgement). Once participants had made their judgement, a 1.5 s central fixation point appeared and was replaced by the next image (images were randomly selected without replacement during the study and test phases).

6.1.2.4 EEG/ERP Acquisition

The scalp ERPs were recorded with 32 Ag/AgCl sensors with integrated noise subtraction circuits (ActiCAP system) fixed onto an electrode cap, according to the International 10-20 System. Electrode impedances were kept below 20kΩ (Kappenman & Luck, 2010). The EEG signal was recorded with a band pass of 0.05 - 100Hz and digitized at a rate of 500Hz. The recording used an average online recording reference and was re-referenced offline to linked mastoids to remain consistent with Voss and Paller (2009). An additional two bipolar electrodes were located above and below the participant's dominant eye and a further two electrodes were located at the outer canthus of each eye. These electrodes were used to monitor and reject eye blinks and horizontal and vertical movements (HEOG and VEOG) not related to the task. H/V EOG electrodes were bipolar resulting in a total of 34 recording channels.

Eye blinks and movements were detected and corrected using the method developed by Gratton, Coles and Donchin (1983). Artifacts were rejected using gradient (60µV step per data point) and amplitude (+/-200µV) criteria. The data were filtered using a Zero-Phase Butterworth filter 0.05-20Hz with a 48dB/octave high pass slope. Following this the data were segmented into epochs lasting 1900 ms (including a 200 ms baseline correction) and averaged according to

stimulus type. Trials in which the participant gave incorrect responses (e.g. falsely identified new image or missed image) were not included in the average. The mean number of artifact free trials with correct answers included in the average for TD individuals, Remember = 270, Know = 105, New = 361 and the respective values for ASD individuals were Remember = 142, Know = 186, New = 346. The mean number of artifact-free trials with correct answers included for the ERP averaging for New items did not differ between the two groups (independent samples t-test (22) < 1.25; $n.s.$), however because of the behavioural difference in Remember and Know judgements that will be described shortly, the number of Remember trials (independent samples t-test (22) = 3.53; p<.05) and Know trials (independent samples t-test (22) = -2.31; p<.05) did differ between groups. Rather than lose data with a weighted average of trials for each condition, all trials were included for the grand average ERP waveform within each condition. The analysis used mean amplitude measures, and the somewhat different trial numbers across conditions was not thought to be particularly problematic (see Luck, 2010).

6.1.2.5 Data Analysis

The raw hit rates for the recognition memory task were corrected by subtracting the proportion of Remember and Know false alarms from the proportion of Remember and Know hits respectively. For the electrophysiological results, mean ERP amplitude measures were computed using two time-windows: 300-500 ms and, 500-700 ms encompassing the latency periods of the mid-frontal Old-New effect and the parietal Old-New effect. A non-overlapping time window was selected to remain consistent with previous research which has used these stimuli (Voss & Paller, 2009). These measurements were performed on the ERP averages for Remembered and Known words separately. It is important to note that a later time window, as in Experiment 1 & 3, was not selected here because the effects of interest in the current experiment were shorter lasting (see results).

To reduce Type 1 error as result of multiple comparisons, electrodes were clustered into three regions of interest; anterior (F3/Fz/F4/FC1/FC2), central (C3/Cz/C4/CP1/CP2), posterior (P3/Pz/P4/O1/Oz/O2) regions (consistent with Voss & Paller, 2009). The magnitude and scalp distribution of Old-New ERP effects between groups were assessed on the ERP difference waveforms. To ensure that topographic comparisons of ERPs were not confounded by differences in the magnitude of the Remember and Know Old-New effects, significant interactions involving Region by experimental, and/or by group factors were further investigated after vector-length normalization of the ERP amplitudes measurements (McCarthy & Wood, 1985).

6.1.3 Results

6.1.3.1 Behavioural Analysis

The corrected data are presented in Table 6.2. These data were entered into a 2 (Group) x 2 (Remember/Know) mixed repeated measures ANOVA. The analysis showed no difference in the proportion of images recognised between groups (F (1, 22) = 3.57, p = *n.s.*). There was a main effect of Remember/Know (F (1, 22) = 17.99, p<.01) where participants gave more Remember judgements than Know judgements. In addition there was a Remember/Know x Group interaction (F (1, 22) = 8.17, p<.01). The interaction was investigated with two independent *t* tests. The TD group made significantly more Remember judgements than the ASD group (*t* (22) = 2.66, p<.05). The ASD group made marginally more Know judgements than TD individuals (*t* (22) = -2.05, p = .06). Overall, the interaction resulted in fewer Remember judgements and more Know judgements being observed for individuals with ASD. A graph showing the interaction can be seen in Figure 6.3.

	TD (N=12)		ASD (N=12)		Both Groups (N=24)	
	M	SD	M	SD	M	SD
Hits						
R	0.58	0.15	0.30	0.28	0.44	0.26
K	0.18	0.12	0.35	0.19	0.26	0.18
R + K	0.76	0.14	0.65	0.16	0.70	0.16
FA						
R	0.06	0.11	0.04	0.19	0.05	0.08
K	0.09	0.08	0.17	0.13	0.13	0.11
R + K	0.15	0.11	0.21	0.13	0.18	0.12
Hits - FA						
R	0.51	0.19	0.26	0.26	0.38	0.25
K	0.09	0.07	0.18	0.13	0.13	0.11
R + K	0.60	0.21	0.44	0.21	0.51	0.22

Table 6.2: Mean and standard deviation of recognition accuracy scores (proportions) for Remember and Know judgements for TD and ASD groups for Experiment 4. R = Remember, K = Know.
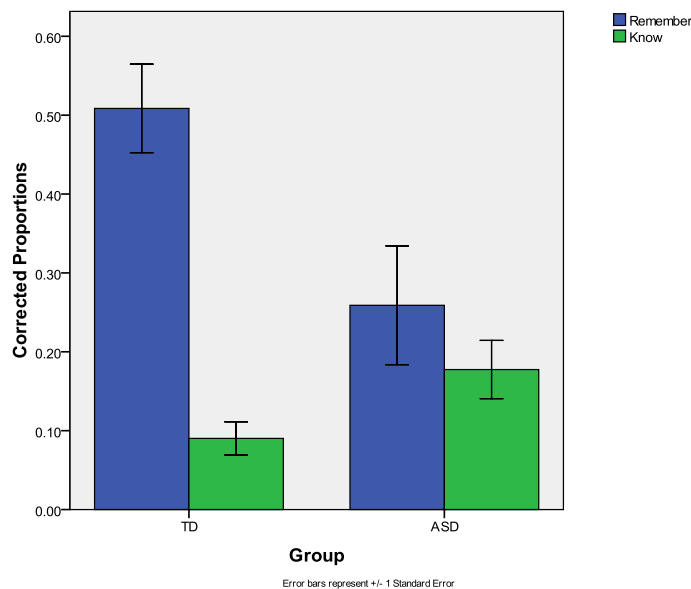
Figure 6.3: Mean proportions of corrected Remember and Know judgements by TD and ASD groups for Experiment 4.

6.1.3.2 ERP Analysis

Description of ERP waveforms

The analyses of the electrophysiological data were conducted to investigate Remember and Know Old-New potential differences between ASD and TD groups. The ERP waveforms to Remembered, Known and New words are shown at all sixteen electrode locations in Figure 6.4.

Amplitude difference topographical maps are presented in Figure 6.5 for the two time windows. These topographical maps plot Remember minus New stimuli amplitude differences alongside Know minus New stimuli amplitude differences. Remember Old-New effects in both groups were characterised by anterior focused positivity from 300-500 ms, which was accompanied by a posterior positivity from 500-700 ms, in line with current literature for parietal Old-New effects, and replicating previous findings (Voss & Paller, 2009). Know Old-New effects also showed anterior focussed positivity from 300-500 ms in line with current literature for mid-frontal Old-New effects for Know judgements. The Know Old-New effect showed anterior focussed Know Old-New effects in the TD group from 500-700 ms, but the topography differed for the ASD group where the effect showed a posterior focus. Both Remember and Know Old-New effects had ended by 700 ms (see Figure 6.4), and no further time windows were selected for ERP analysis.
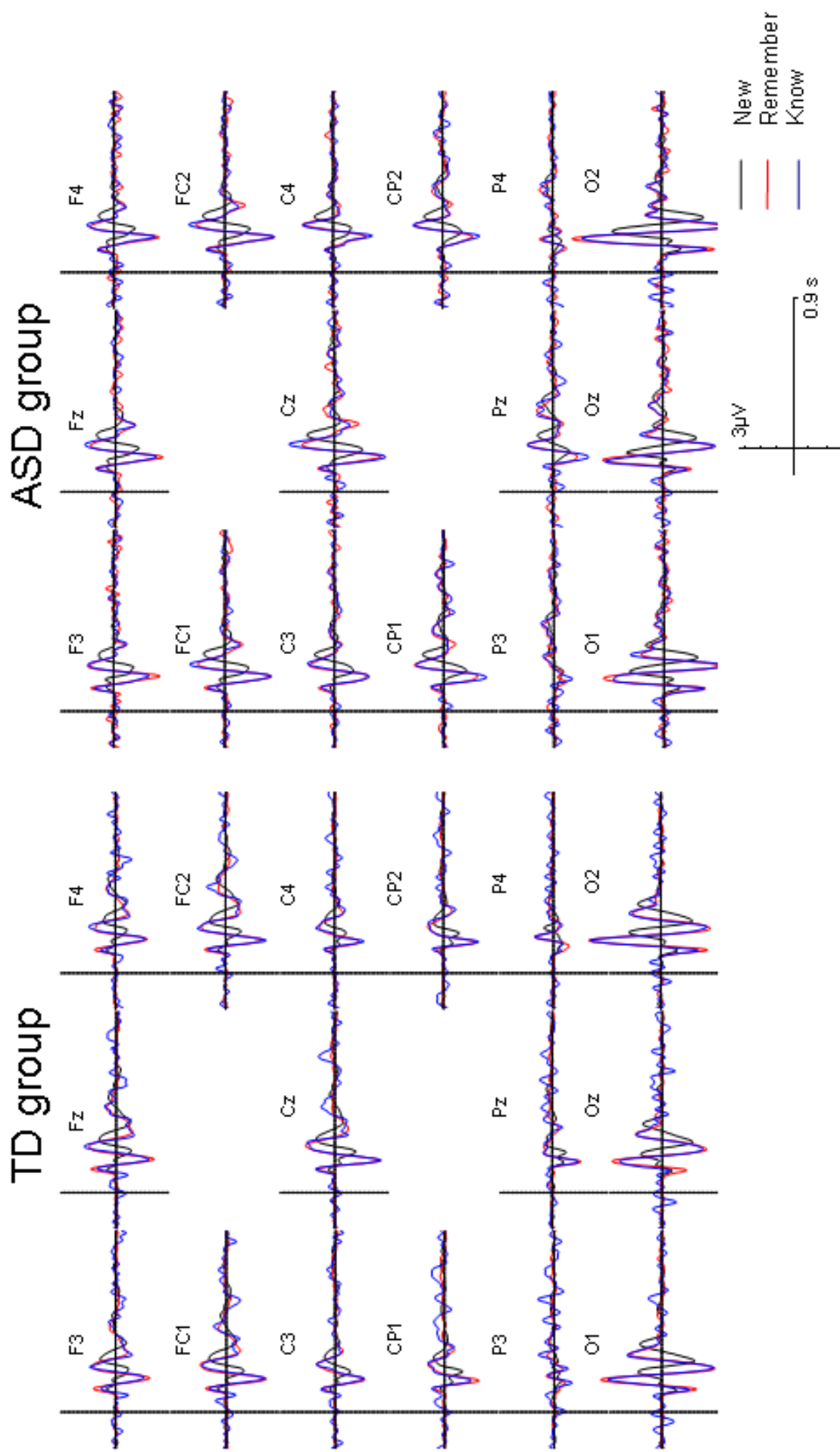
Figure 6.4: Remember and Know ERP Old-New effects for TD (N=12) and ASD (N=12) groups for Experiment 4 shown at all sixteen electrodes. Remember ERPs are presented in red, Know ERPs are presented in blue and New image ERPs are presented in black.
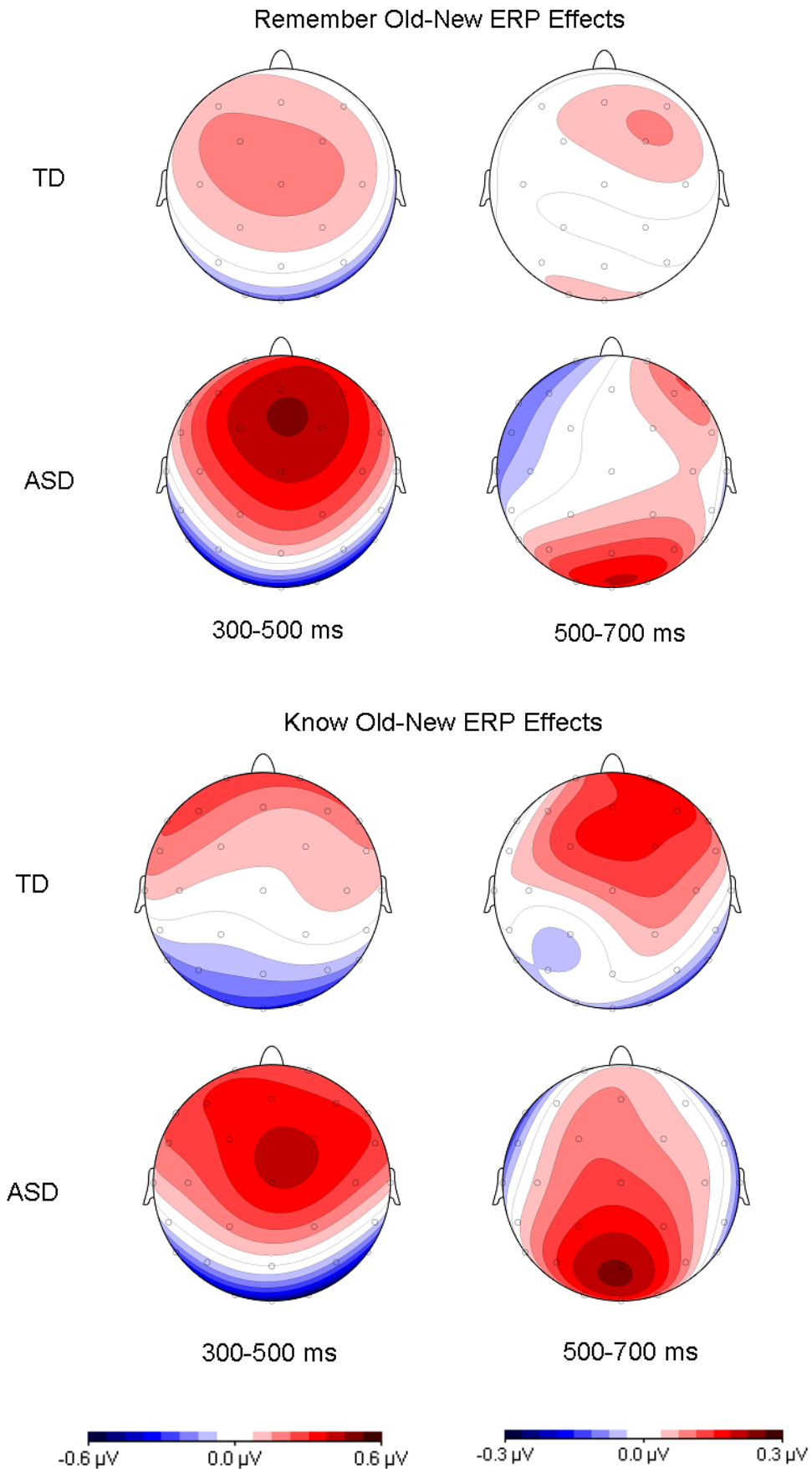
Figure 6.5: 2D scalp maps of Remember and Know Old-New effects from 300-500 ms and 500-700 ms for TD (N = 12) and ASD (N = 12) groups for Experiment 4.

ERP Analysis

Preliminary analyses revealed that Remember Old-New effects (F (1, 22) = 20.04, p<.01) and Know Old-New effects (F (1, 22) = 13.61, p<.01) were significant in both time windows. The amplitude differences were larger in the ASD group compared to TD individuals leading to Old-New effect x Group interactions for both Remember (F (1, 22) = 6.83, p<.05) and Know (F (1, 22) = 4.61, p<.05) responses. In order to further explore these differences as a function of scalp topography and latency, the data were entered into a 3 Region (anterior/middle/posterior) x 2 Latency (300-500 ms /500-700 ms) x 2 Remember/Know x 2 Group mixed Repeated Measures ANOVA. The mean and standard deviation amplitudes for each region of interest at each time window can be seen in Table 6.3

			TD (N=12)		ASD (N=12)	
			M	SD	M	SD
300-500ms	Remember	Anterior	0.18	0.21	0.68	0.55
		Middle	0.18	0.18	0.56	0.49
		Posterior	-0.10	0.22	0.02	0.51
	Know	Anterior	0.14	0.46	0.49	0.43
		Middle	0.05	0.49	0.42	0.31
		Posterior	-0.20	0.41	-0.14	0.57
500-700ms	Remember	Anterior	0.11	0.23	0.22	0.32
		Middle	0.07	0.25	0.24	0.25
		Posterior	0.09	0.19	0.35	0.22
	Know	Anterior	0.22	0.30	0.22	0.35
		Middle	0.14	0.28	0.28	0.43
		Posterior	0.07	0.22	0.32	0.36

Table 6.3 Means and standard deviations for the amplitude differences at each region of interest in the TD and ASD groups for Experiment 4. Amplitude measures are in µV.

The results confirmed that Old-New potential differences were larger for ASD individuals than TD individuals (F (1, 22) = 9.55, p<.01) overall with an average amplitude difference in the TD group of 0.08 µV and of 0.31 µV in the ASD group. The main effect of Region was significant (F (1.28, 28.26) = 28.55, p<.01), and this was qualified by a significant Latency x Region interaction (F (1.26, 27.60) = 14.59, p<.01) and Latency x Remember/Know x Region interaction (F (2, 44) = 5.11, p = .01). To investigate the three way interaction further, amplitude difference values for Remember and Know Old-New effects in each time window were entered into mixed repeated measures ANOVAs with the factors Region (anterior/middle/posterior) and Group.

Remember Old-New effects

From 300-500 ms Remember Old-New differences were larger in the ASD group (0.42

μV) compared to the TD group (0.27μV), (F (1, 22) = 4.98, p<.05), although topographically the effect showed an anterior focus in both groups (F (1.21, 26.63) = 38.59, p<.01). From 500-700 ms the scalp topographical maps also showed that the Remember Old-New effect was positive going in both groups. The main effect of Region was not significant in this time window (F (1.51, 33.31) = 1.50, p = *n.s.*), suggesting that the effect was widespread.

Know Old-New effects

For the 300-500 ms window, Know Old-New effects showed an anterior focus that was observed in both groups (main effect of Region F (1.30, 28.50) = 17.48, p<.01), which is in line with current literature for the mid-frontal Old-New effect. The topography of the Know Old-New effect in the 500-700ms window, however, was marginally different between groups (F (1.29, 28.34) = 3.47, p = .06) where the effect showed an anterior focus in the TD group but showed a posterior maximum for ASD individuals.

Summary

Old-New effects were significantly larger in the ASD group than TD group across both time windows. Remember Old-New effects were comparable between groups and were characterised by an early anterior focus followed by a later widespread positivity. Know Old-New effects for TD and ASD individuals showed an early anterior focus. The anterior positivity continued in the TD group from 500-700 ms whilst in the ASD group the effect showed a posterior maximum.

6.1.4 Discussion

The main aim of this experiment was to investigate if attenuated Old-New effects in ASD (Experiment 1 and 3) resulted from difficulties with processing linguistic verbal stimuli in the ASD group. Novel, non-nameable kaleidoscope images were used for this experiment. The behavioural results replicate a pattern of recognition performance observed in the current literature (Bowler et al., 2000a, b, 2007), by confirming that overall recognition is preserved in ASD but that it is characterised by diminished episodic Remember and increased semantic Know responses. For the TD group, ERP Old-New effects replicated earlier findings (Voss & Paller, 2009) of an anterior focused positivity from 300-500 ms and a more widespread positivity at anterior and posterior regions from 500-700ms. In contrast to Experiments 1 and 3 where verbal stimuli were used and where ERP Old-New effects were diminished in ASD (particularly for Remembering), the ERP data in the current experiment demonstrated enhanced Old-New effects in the ASD group across both Remember and Know responses. Similar to the earlier experiments, however, Remember Old-New effects exhibited similar scalp topographies in the two groups, whilst Know Old-New effects tended to be somewhat differently distributed across electrode sites. Importantly, the stimuli in this experiment were novel images unknown to the

participants, thereby eliminating the possibility that participants attributed noetic awareness from outside the experiment to the experimental study phase (addressing a potential limitation of the previous studies reported in this thesis). Know Old-New effects reported in this experiment are therefore unlikely to be a result of previous experience with well-learnt word stimuli.

The present finding of no diminished Old-New effect in the ASD group for non-nameable and non-verbal stimuli provides evidence to suggest that the attenuation of the Old-New effect observed in Experiments 1 and 3 may be specific to language-related tasks. This suggestion would resonate with the findings of reduced N400 effects observed for verbal semantic incongruence in ASD, but typical N400 effect for non-verbal (environmental and sound) pairings (McCleery et al., 2009). Moreover, as we have already seen, specific difficulties with the processing of verbal semantic incongruence and reduced N400 effects have been reported previously (Ring et al., 2007; Strandburg et al., 1993; Pijnacker et al., 2010; Dunn et al., 1999), including observations of diminished N400 effects for word-pairs, alongside typical amplitudes on non-verbal tasks such as the continuous performance task, the span of apprehension task and the idiom recognition task (Strandburg et al., 1993). The results from these studies, and the findings from the current study, provide strong evidence to suggest that memory-related ERP differences in ASD are particularly apparent during the processing of verbal stimuli.

The question of why Old-New effects were enhanced in the ASD compared to TD group in the current study arises. One explanation is provided by Sternberg, Johansson and Rosen (2006) who identified larger positive amplitude differences in the Old-New effect for pictures compared to words in a TD sample of individuals. The authors suggest that these results were observed because new pictures can more easily be rejected on perceptual grounds than new words (Sternberg, Johansson & Rosen, 2006). It has been found that individuals with ASD demonstrate superior performance in their perceptual functioning ability (see Mottron et al., 2006) as well as superior discrimination in low level processing abilities for visual stimuli (see Bertone, Mottron, Jelenic & Faubert, 2005). As a result of these differences it is possible that New non-nameable images were more easily rejected in this group compared to the TD group. TD individuals may instead favour strategies such as attaching verbal labels to stimuli to support recognition, which is a strategy not readily afforded by the stimuli used in the present task. Further studies that explicitly investigate the strategies individuals used to memorise the stimuli will be needed in order to clarify this.

Know Old-New amplitude differences showed anterior focussed positivity from 300-500 ms in both groups, in line with current literature for the mid-frontal Old-New effect. Know Old-New effects were also significantly larger in the ASD group than TD group, but in addition were also characterised by altered scalp topography. Following the mid-frontal Old-New effect, TD

individuals displayed continued anterior positivity from 500-700 ms, whilst the offset of the Know ERPs showed increased posterior activity in the ASD group. This was a marginal group difference and must be treated with caution, however it suggests that the ASD group were using different neural mechanisms or strategies to aid their Know responses. Differences in Know Old-New effects were also observed for word stimuli in Experiment 3, where late anterior negativity for Know judgements was observed in ASD compared to TD individuals. In addition, Experiment 1 also revealed Old-New topographical differences between ASD and TD groups in an early time window often associated with the semantic memory system. Together these findings provide very convincing evidence of differing functional neurophysiology operating for semantic Know judgements in ASD, which may underlie the behavioural increase in Know responses observed in this population. Of interest remains why group differences in Experiment 3 and 4 did not fall within the typical time window of Know Old-New ERP effects (mid-frontal Old-New effect 300-500 ms).

Know Old-New effects in the ASD group included posterior positivity from 500-700 ms, appearing remarkably similar to Remember Old-New effects in the TD group. It may be the case that individuals with ASD engaged neural systems typically associated with Remembering in order to compensate for dysfunctional semantic processes. Future studies using neuro-imaging techniques (such as fMRI) would help to clarify this. Another possibility is that the ASD group may have been mislabelling Remember judgements as Know judgements. However, it is unlikely that the ASD group experienced autonoetic conscious remembering during these responses as the behavioural data demonstrated that Know responses for both groups were characterised by an inability to recall specific contextual information from the study phase. It is also important to note that participants' responses were assessed for consistency during an interactive practice block prior to the task and a questionnaire (see Appendix 2).

In conclusion, the present experiment demonstrated that the diminished Old-New ERP effects seen in Experiment 1 for the ASD group are not only eliminated but reversed, to an enhancement with non-nameable, novel images. These findings provide evidence to suggest that diminished Old-New effects for word stimuli in ASD can be attributed to difficulties with processing nameable and verbal stimuli. Old-New effects for Remember and Know judgements were enhanced in ASD and may reflect the enhanced propensity for this subgroup to reject New images on perceptual grounds compared to the TD group. Although Experiment 3 revealed an anterior negativity for semantic Know judgements in the ASD group that was not observed here (likely due to the different types of stimuli employed), the topographical differences between groups for Know but not Remember recognitions in the current study, provide further evidence for the suggestion that the semantic memory system is compromised in ASD.

Chapter 7 : CONVERGING EVIDENCE USING THE INCLUSION/EXCLUSION PARADIGM

7.1 Experiment 5

7.1.1 Introduction

The experiments reported so far have broadly confirmed the Remember/Know difference in ASD (Experiments 2 and 4, but not Experiment 3). These studies have also established that the Old-New ERP effect is overall diminished for words and nameable stimuli in ASD and that atypical Know ERPs underlie this attenuated Old-New effect in recognition. However, Experiments 1 to 4 in the current thesis have exclusively employed Remember/Know paradigms, which are based on certain assumptions about the operation of recognition memory that not all memory theorists agree with (see section 3.2). To reinforce the validity of the observations so far, therefore, it is important to extend the foregoing experiments with alternative paradigms thought to probe episodic and semantic memory.

As discussed in Chapter 3, study items can be assigned an 'experimental context' for which memory can be subsequently tested. In one test procedure, Wilding and Rugg (1996) asked participants to memorise a list of items which were presented in two different modalities (presented by two different speakers, one male and one female). During test, participants were asked to make Old/New judgements to stimuli and to those judged Old, provide the context in which it was studied (either male or female voice). As the recollection of contextual information from the study episode is the hallmark of autonoetic Remembering, the ERP effects associated with these judgements are thought to indicate brain activity associated with the episodic memory system. In contrast, Old stimuli that are recognised without the retrieval of contextual information reflect contributions of noetic awareness/knowing, and ERP effects associated with these responses reflect contributions from the semantic memory system. Unlike the Remember/Know paradigm, these tasks define specific attributes of the stimuli which constitute episodic recollections (in the example above, the voice of the speaker). The retrieval of 'non-diagnostic' contextual information relating to the initial study phase, for example, idiosyncratic experiences does not count towards a Remember response. Providing an experimentally defined context therefore results in a stringent measure of episodic remembering.

The sequential response method described above (Old/New followed by Source 1/Source 2 judgment) has been supplemented by more direct tests of context recollection. For example, Senkfor and Van Petten (1998) used a three button response (Source 1/ Source 2/ New) and Wilding and Rugg (1997) used a two button (Target/ Non-target and New) response. The ERP

findings for Item and Context judgments have had converging findings with that from other paradigms, however there are some differences that are most probably attributable to the differences between the experimental tasks and/or characteristics of the stimuli (Cycowicz, 2001). Two ERP Old-New effects have been consistently observed. The first Old-New effect has a posterior topography, is positive going and has an onset of approximately 300 ms (Cycowicz, Friedman & Snodgrass, 2001). This ERP has been associated with the retrieval of item content (which can be accompanied by contextual information or not, see Wilding & Rugg, 1997; Trott et al., 1999). A second ERP effect has been reported alongside (Wilding & Rugg, 1997), or subsequent to the parietal Old-New effect (Trott, Friedman, Ritter & Fabiani, 1997; Wolk et al., 2009). This ERP has a prefrontal scalp distribution and is often right lateralised. Wilding and Rugg (1996) interpret this late prefrontal Old-New effect as the search and retrieval of contextual information relating to the stimuli suggesting that this ERP may be associated with the retrieval of episodic memories. This interpretation is consistent with neuro-imaging data (fMRI) which has implicated a role for the right prefrontal cortex in episodic memory (Buckner & Tulving, 1995; Wagner, Desmond, Glover & Gabrieli, 1998; DeVito & Eichenbaum, 2010).

Cycowicz et al. (2001) employed the Inclusion/Exclusion paradigm (Jacoby, 1991) to determine brain signatures for recognition (1) void of contextual information from the study phase (Item memory task) and (2) accompanied by the retrieval of contextual information (Context memory task). In their study, the authors used line-drawings of common nameable objects presented in one of two coloured outlines. Participants were asked to memorise both the image and its coloured outline for a later memory test. At test participants were assigned a 'Target' colour (one of the two colours from the study phase), and all images were presented in a black outline. Participants were then presented with a series of Old/New test blocks and Target/Other test blocks. The Old/New judgement (*inclusion task*) required the inclusion of all studied stimuli into the 'Old' category (hereafter Item memory test). The Target/Other judgement (*exclusion task*) required the successful exclusion of all stimuli that were not studied in the participants target colour, i.e., images studied in the Non-target colour and New images into the 'Other' category (hereafter the Context memory test). Although above chance performance on the Item memory task could be achieved without episodic recollection (semantic memory alone would suffice, i.e., knowing the image was encountered during the study phase and successfully responding 'Old'), above chance performance on the Context memory task could only be achieved if participants were able to distinguish between the two classes of Old stimuli (Targets and Non-targets), and recollect their presentation colour from the study phase. The authors used this distinction to identify different scalp distributions for Item and Context memory tasks (consistent with previous research, Wilding & Rugg, 1997; Trott et al., 1997). Correctly recognised Items demonstrated early posterior Old-New effects beginning 300 ms regardless of whether they were items recognised during the inclusion task or as Targets or Non-targets during

the exclusion task. Target and Non-target ERP Old-New effects (judgements that were associated with the successful recollection of study context) demonstrated later long duration occipitally focused negativity beginning 800 ms. This posterior activity is thought to result from the use of a distinct perceptual attribute (colour) to define the context of the line-drawings (Cycowicz et al., 2001). Cycowicz and colleagues also highlighted a simultaneous anterior positivity for trials in which correct source judgements were made, and the authors suggest that the combined posterior negativity and anterior positivity reflects the retrieval of stored representations from the occipital cortex (colour information) under the direction of the prefrontal cortex (see Squire & Kandel, 1999). The ERPs observed are unlikely to be due to the retrieval of the pictures *per se*, because in their study, the posterior negativity was not observed for Item recognition ERPs, suggesting that this activity reflects a material specific search for contextual information (Cycowicz et al., 2001).

In their study Cycowicz et al. (2001) grouped successfully recognised Targets and Non-targets into a category of ERP they assumed reflected episodic memory judgements. However, in a more recent study Herron and Rugg (2003) have suggested that recollection (episodic memory) is not a requirement for the successful exclusion of Non-targets. In Herron and Rugg's study participants were given two blocks of study items. One block consisted of 'to-be-excluded' Non-targets and one block comprised 'to-be-remembered' Targets. In one condition of the study, instructions for Non-targets and Targets were identical; participants were asked to create a sentence using a word that appeared on a screen. The results showed that Target recognition was accompanied by parietal Old-New effects, but this effect was absent for Non-targets. In a second condition, the study instructions for Target items differed; participants were asked to give a pleasantness rating for the word. In this condition both Targets and Non-targets were accompanied by parietal Old-New ERP effects, indicating that episodic recollection accompanied both these judgements. Taken together, these results suggest that participants' successful Non-target exclusion was completed using different processes in the two conditions, one reliant on episodic retrieval of how words were encoded, and the other not. This provides evidence to suggest that episodic memory does not always accompany Non-target recognition, and on some occasions (depending on the task demands) Non-target recognition can be completed without the recollection of contextual detail from the study episode.

One further concern for grouping Target and Non-target recognition concerns the methods used by participants to fulfil the task demands. Given that successful Non-target recognition requires the participant to respond 'Other' to items that were not presented in their Target colour, correct exclusion of a Non-target may be achieved by one of two strategies. One possibility is that participants successfully recalled the presentation colour of the item as their Non-target and responded accordingly, or they forgot the item and responded 'Other' because

they believed it to be a New item. Furthermore if a very conservative response criterion was adopted by participants, Non-target recognition could have been achieved without Remembering the colour of the presented image. For example, if a participant only responds 'Target' to an image they remember as being presented in their Target colour and 'Other' to everything else, they would correctly reject Non-targets without necessarily remembering that they were not presented in the target colour. In light of these arguments and those from the preceding paragraph, the present experiment did not collapse Target and Non-target recognition ERPs as in Cycowicz et al. (2001) and instead these were analysed separately.

The aim of the current experiment was to investigate three ERP Old-New effects in ASD using the Inclusion/Exclusion paradigm; (1) the early positive Old-New effect for Item recognition, (2) the late posterior negative Old-New effect for Context memory, and (3) the late anterior positive Old-New effect for Context memory.

7.1.2 Method

7.1.2.1 Participants

Fifteen ASD participants (2 females) and 18 TD participants (2 females) took part in the experiment. Participants were recruited through a database at City University London. The ASD group all had clinical diagnoses which were made by professionals experienced in the field of Autism. The ASD group all met DSM-IV- TR (2000) criteria for the Autism Spectrum Cut off on the ADOS-G. All participants were right handed and reported normal or corrected to normal vision. Participants were individually matched for Verbal and Full-scale IQ using the WAIS-III-R scales of intelligence to within 7 points, and group matched for Performance IQ, Age and Gender. Averages for the participants AQ, Age, VIQ, PIQ and FIQ for both groups are presented in Table 7.1. Participants were paid standard university fees for their time and reimbursed travel costs. The experiment was approved by the ethics committee at City University London.

	ASD (N=15)		TD (N=18)	
	M	SD	M	SD
Age (years)	38.89	14.77	37.17	11.84
VIQ	114	11	111	17
PIQ	111	14	109	16
FIQ	114	13	111	18
AQ	35	7.08	16	6.14

Table 7.1: Mean and standard deviation for Age, AQ and IQ measures (WAIS-III-R). VIQ = Verbal IQ, PIQ = Performance IQ, FIQ = Full-scale IQ for Experiment 5.

7.1.2.2 Stimuli

Experiment images comprised 300 line-drawings of common objects selected from the normative databases of Snodgrass and Vanderwart (1980) and Cycowicz, Friedman, Rothstein and Snodgrass (1997). Examples of the stimuli can be seen in Figure 7.1. The 300 images were divided into 6 blocks of 50 that were matched on name agreement, familiarity, visual complexity and category membership. Statistical analyses of these variables revealed no significant differences across blocks or across items that were to be selected as the study and test images (all p's> .05). Each participant viewed 6 blocks, in a block-designed experiment. The block consisted of a short study phase, followed by Item memory and Context memory test phases. Thirty-two study images were presented (16 presented in red and 16 in blue). Of the 32 study images, 12 were assigned to the Item memory test phase and 20 to the Context memory test phase (only 10 of which were presented in the participant's target colour for that block). There were 18 New images, 12 were assigned to the Item recognition test and 6 to the Context memory test. This resulted in a total of 24 test images being presented in the Item memory phase and 26 test images in the Context memory phase, for each block. All test phase images were presented in black. Each ASD participant and their matched TD participant viewed the same randomised order of experimental blocks.
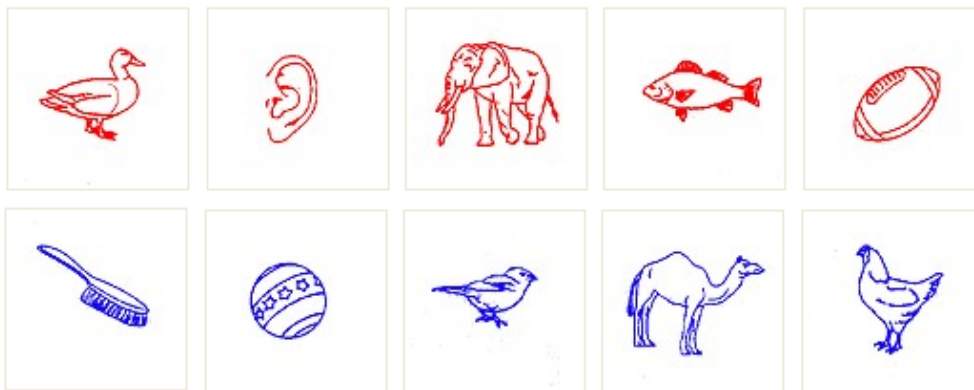
Figure 7.1: Examples of stimuli used in Experiment 5.

7.1.2.3 Presentation

Participants were asked to study a list of images presented one at a time, and given instructions to memorise not only the image but also the colour of the image (either red or blue) for a later memory test. Special emphasis was placed on remembering both components of the stimuli. During the Item memory test, images were presented in black and participants had to make Old-New discriminations. They were asked to press 'Old' if they thought the image was seen during the study phase and 'New' if they thought the image did not appear during study. Before each Context memory test block participants were assigned a 'Target' colour (in half of the test blocks red was the target colour and in half it was blue). Instructions were to respond

'Target' to all images presented during the study phase in the participant's target colour and respond 'Other' to all other stimuli (i.e. new images or those not presented in the target colour). Participants completed a practice block before the electrode cap was fitted. Response buttons and the presentation of Item and Context memory test blocks were counterbalanced.

The experiment took place in a dimly lit and sound attenuated EEG laboratory. Participants sat directly opposite a 15 inch computer screen which presented all stimuli at a viewing distance of 70cm. Images were presented as large as possible inside a frame which measured 6.5 x 6.5 cm. This resulted in a visual angle of 5.32⁰. During study, images were presented at a rate of one every 3s (500 ms central fixation cross and 2500 ms study image presentation). During the Item and Context memory test, images were presented at a rate of one every 2.5s (500 ms central fixation cross and 2000 ms image presentation).

7.1.2.4 EEG/ERP Acquisition

The scalp ERPs were recorded with 32 Ag/AgCl sensors with integrated noise subtraction circuits (ActiCAP system) fixed onto an electrode cap, according to the International 10-20 System. Electrode impedances were kept below 20kΩ (Kappenman & Luck, 2010). The EEG signal was recorded with a band pass of DC - 100Hz and digitized at a rate of 500Hz. The recording used an average online recording reference. An additional two bipolar electrodes were located above and below the participant's dominant eye and a further two electrodes were located at the outer canthus of each eye. These electrodes were used to monitor and reject eye blinks and horizontal and vertical eye movements (HEOG and VEOG) not related to the task. H/V EOG electrodes were bipolar resulting in a total of 34 recording channels.

Eye blinks and movements were detected and corrected using the method developed by Gratton, Coles and Donchin (1983). Artifacts were rejected using gradient (60μV step per data point) and amplitude (+/-200μV) criteria. The data were filtered using a Zero-Phase Butterworth filter 0.05-20Hz with a 48dB/octave high pass slope. Following this the data were segmented into epochs lasting 1500 ms (including a 200 ms baseline correction) and averaged according to stimulus type. Trials in which the participant gave incorrect responses (e.g. falsely identified new item/ missed item or incorrectly endorsed target item /missed target item) were not included in the average.

7.1.2.5 Data Analysis

For the behavioural data, the raw hit rates for the Item recognition memory task were corrected by subtracting the proportion of Item false alarms from the proportion of Item hits. The raw hit rates for the Context memory task were corrected by subtracting the proportion of

Target/Non-target false alarms from the proportion of Target/Non-target hits respectively.

For the electrophysiological results, mean ERP amplitude measures were computed at each scalp electrode using two time-windows: 300-650 ms and 950-1200 ms encompassing the latency periods of the Item Old-New effect and Context Old-New effect reported by Cycowicz et al. (2001). These measurements were calculated for the ERP averages for Item, Target and Non-target Old and New images. To reduce Type 1 error as result of multiple comparisons, electrodes were clustered into nine scalp regions of interest; left, midline and right sagittal planes and anterior/central/posterior regions. The analyses were performed on data gathered from 32 scalp electrodes along anterior, central, posterior regions and left, midline and right sagittal planes (following Cycowicz et al., 2001). The 32 scalp sites included the regions anterior left (FP1/F7/F3/FC5), anterior midline (FC1/FC2/Fz), anterior right (FP2/F4/F8/FC6), central left (T7/TP9/CP5), central midline (CP1/CP2/Cz), central right (TP10/CP6/C4/T8), posterior left (P7/P3/PO9/O1), posterior midline (Pz/Oz) and posterior right (P9/P4/PO10/O2). The magnitude and scalp distribution of Old-New ERP effects between groups were assessed on the ERP difference waveforms.

7.1.3 Results

7.1.3.1 Behavioural Results

The corrected data were entered into a 3 (Item/Target/Non-Target) x 2 Group repeated measures ANOVA. There was a main effect of Item/Target/Non-Target ($F_{(2, 30)} = 39.47$, $p<.01$) where overall corrected Item recognition ($M = 0.72$) accuracy was greater than Target ($M = 0.39$) and Non-target recognition ($M = 0.39$). There was no Item/Target/Non-target by Group interaction ($F_{(2, 30)} = 0.78$, $p = $ *n.s.*), although it is worth noting that proportionally, the Target items proved by far the most difficult for individuals with ASD. The main effect of Group approached significance ($F_{(1, 31)} = 3.64$, $p = 0.07$), where corrected recognition was marginally higher in the TD group (0.59) compared to the ASD group (0.41), indicating that all three tasks were more difficult for ASD individuals compared to TD individuals. The data are presented in Table 7.2.

	TD (N=18)		ASD (N=15)		Both Groups (N=33)	
	M	SD	M	SD	M	SD
Item Recognition						
Old	0.87	0.11	0.79	0.16	0.84	0.14
FA	0.08	0.07	0.16	0.12	0.12	0.11
Old - FA	0.79	0.15	0.63	0.23	0.72	0.21
Target Recognition						
Old	0.56	0.23	0.36	0.34	0.47	0.30
FA	0.06	0.11	0.09	0.13	0.07	0.12
Target - FA	0.50	0.23	0.27	0.40	0.40	0.35
Non-target Recognition						
Old	0.51	0.32	0.42	0.32	0.47	0.32
FA	0.06	0.11	0.09	0.13	0.07	0.12
Non-target - FA	0.45	0.37	0.33	0.41	0.40	0.39

Table 7.2: Mean and standard deviation of recognition accuracy scores (proportions) for Old Items, Targets and Non-targets and False Alarms (FA) for TD and ASD groups in Experiment 5.

False Alarms (FA)

The FA data from the Item and Context memory test blocks were entered into a 2 Task (Item FA/ Context FA) x 2 Group mixed Repeated Measures ANOVA and revealed a main effect of Task ($F_{(1, 31)} = 8.46$, $p<.01$), where the proportion of Item FA was higher (0.13) than Context FA (0.08). The Task x Group interaction was significant ($F_{(1, 31)} = 4.76$, $p <.05$). One-way ANOVAs for each Task showed that the ASD group made more FAs during the Item task compared to the TD group ($F_{(1, 31)} = 4.79$, $p<.05$), mean proportion of FAs for ASD individuals was 0.16 and for TD individuals was 0.09. Context memory FAs remained comparable across groups ($F_{(1, 31)} = 0.46$, $p = $ *n.s.* ASD group mean = 0.09, TD group mean = 0.08).

7.1.3.2 ERP Results

The analysis of the electrophysiological data was conducted to investigate Old-New potential differences between ASD and TD groups for the three classes of stimuli. Trials corresponding to Item, Target and Non-target recognition were analysed separately. For the Item memory task, ERPs for correctly identified Items were plotted against correctly rejected New

items from the Item memory test block. Correctly identified Target and Non-target items were plotted against correctly rejected New items from the Context memory test block. To investigate the differences in the magnitude of these ERP Old-New effects between groups, difference waveforms were calculated (Old minus New amplitudes). The mean number of artifact free trials with correct answers included in the average for TD individuals were, Item = 42, Target = 21, Non-target = 21, (Item) New = 57, (Context) New = 31, and for ASD individuals were, Item = 43, Target = 19, Non-target = 19, (Item) New = 56, (Context) New = 29. The mean number of artifact-free trials with correct answers included for the ERP averaging did not differ between the two groups ($t(31) = 0.14$, p = *n.s.*; Target $t(31) = 1.42$, p = *n.s.*; Non-target $t(31) = 0.83$, p = *n.s.*; Item New $t(31) = 0.14$, p = *n.s.*; Context New $t(31) = 1.06$, p = *n.s.*). The ERP waveforms for the Item Old-New effects for both groups can be seen in Figure 7.2. Target and Non-target Old-New effect ERPs can be seen in Figure 7.3.

Description of ERP waveforms

For TD individuals early Old-New effects (300-650 ms) were observed for Item, Target and Non-target recognition. The effect was observed at right anterior, central and posterior regions. For ASD individuals early Old-New effects appeared diminished for all three classes of stimuli (see Figure 7.2). Both groups demonstrated posterior negativity and anterior positivity for Target and Non-target Old-New effects (950-1200 ms, see Figure 7.3). The ERP data for each group, from 300-650 ms is presented in Figure 7.4, and from 950-1200 ms is presented in Figure 7.5.

Item Recognition Old-New effects

TD group

ASD group
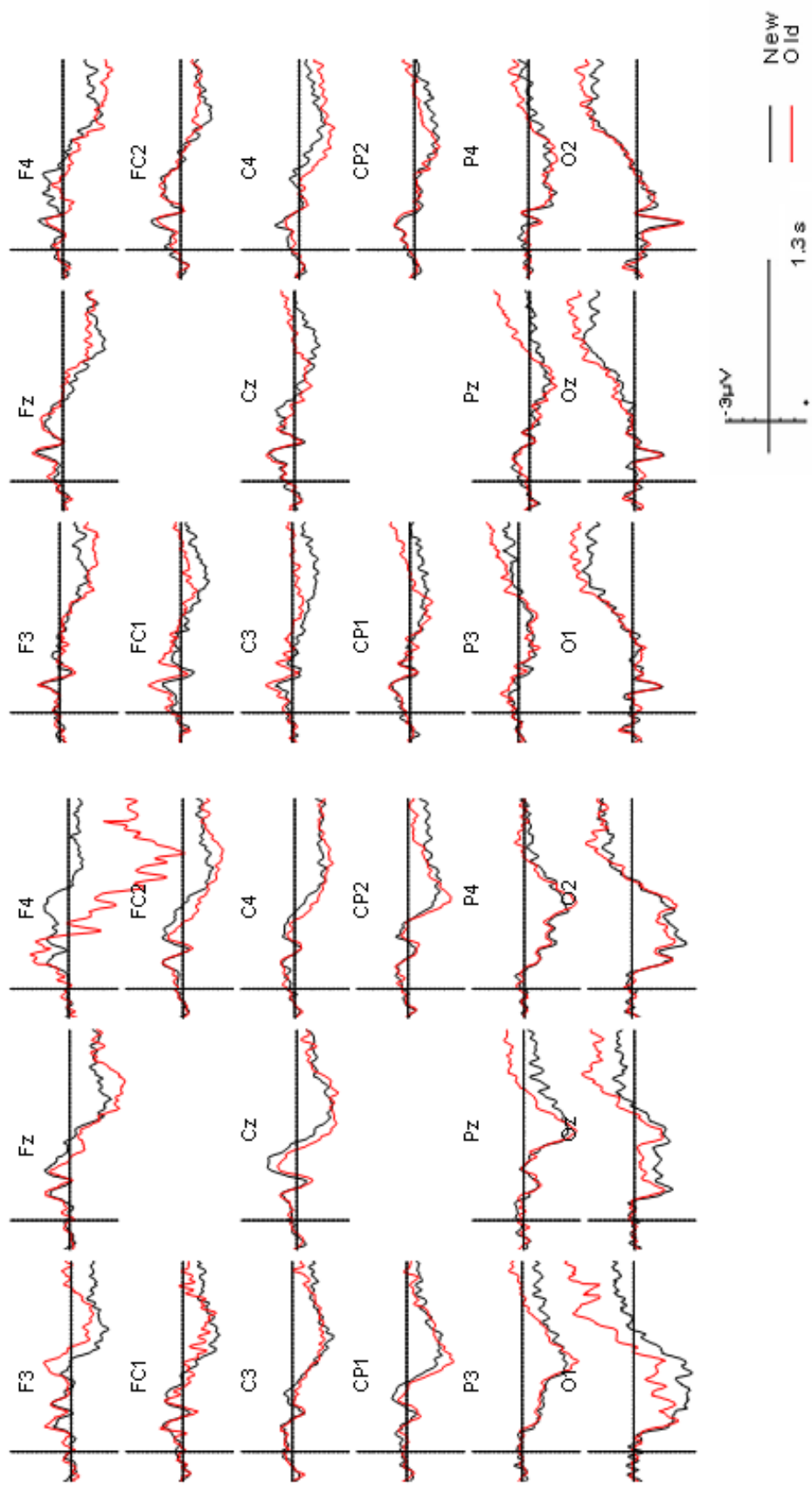
Figure 7.2:Item Old-New effects for TD (N=18) and ASD (N=15) groups for Experiment 5 shown at sixteen selected electrodes. Item ERPs are presented in red, New image ERPs are presented in black.
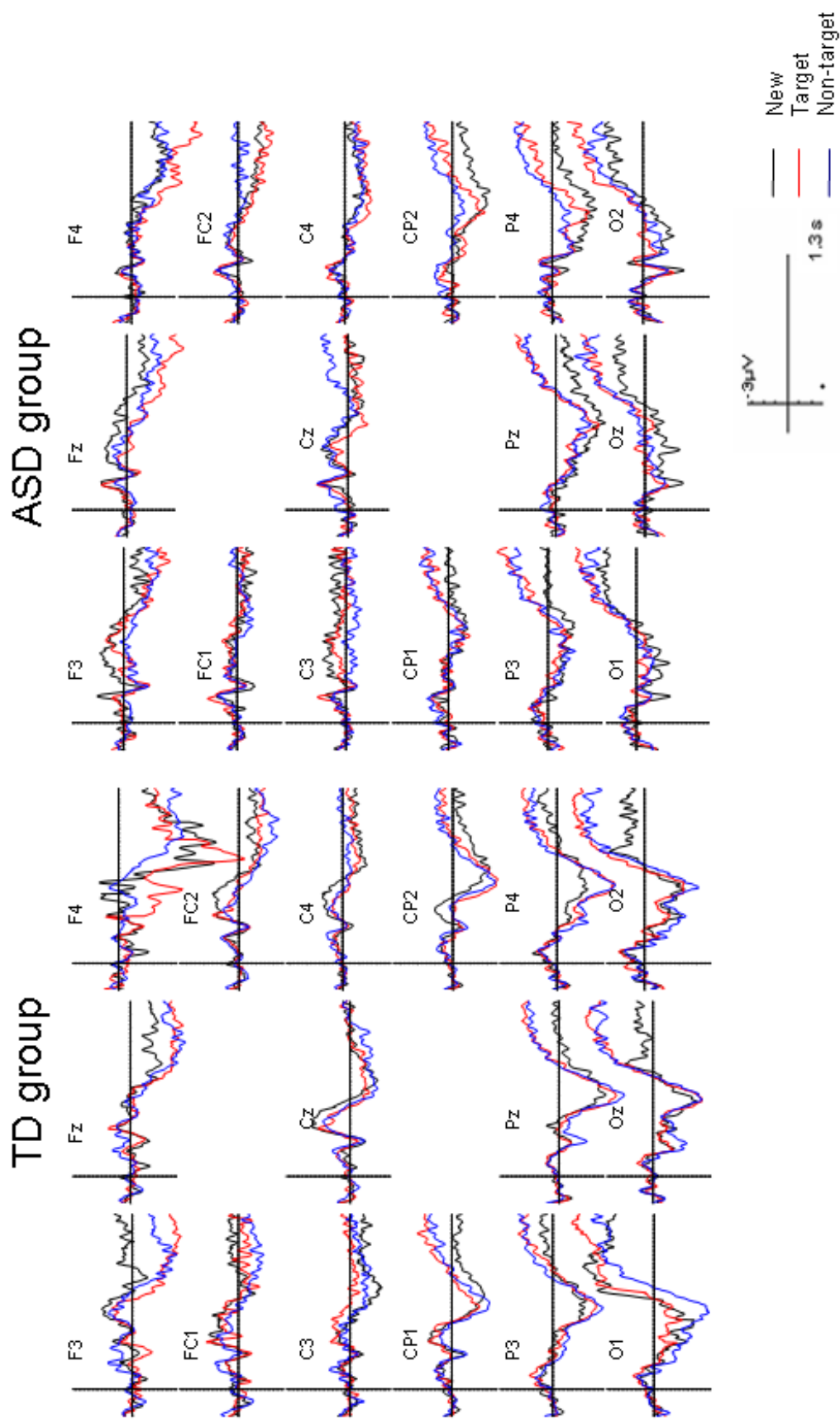
Figure 7.3: Target and Non-target ERP Old-New effects for TD (N=18) and ASD (N=15) groups for Experiment 5 shown sixteen selected electrodes. Target ERPs are presented in red, Non-target ERPs are presented in blue, New image ERPs are presented in black.

Item, Target and Non-Target Early Old-New ERP Effects (300-650ms)
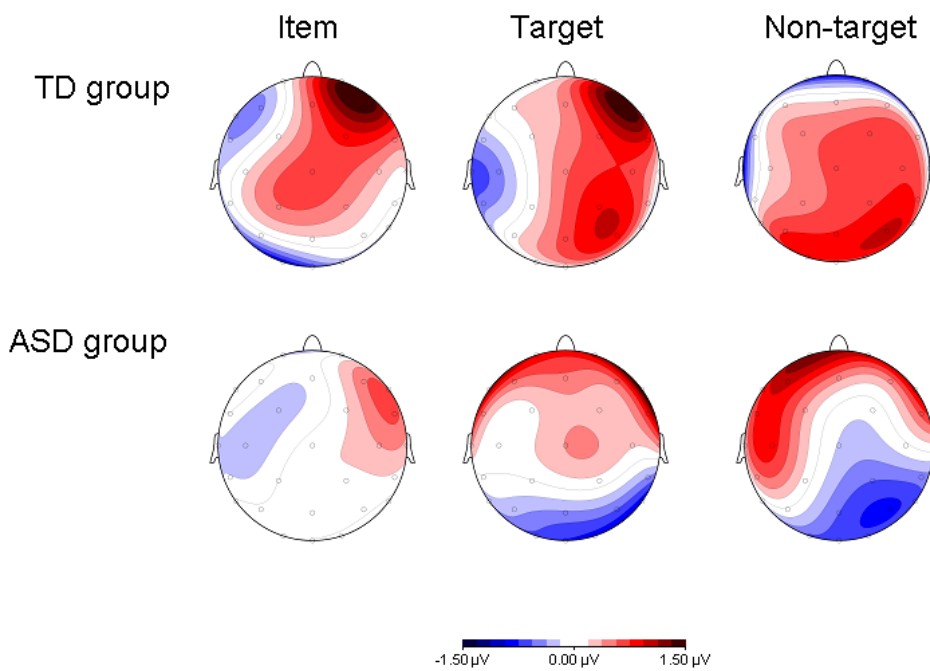
Figure 7.4: 2D scalp distributions of Item, Target and Non-target Old-New ERP amplitude differences (Old minus New words) from 300-650 ms for TD (N = 18) and ASD (N = 15) groups for Experiment 5.

Item, Target and Non-Target Late Old-New ERP Effects (950-1200ms)
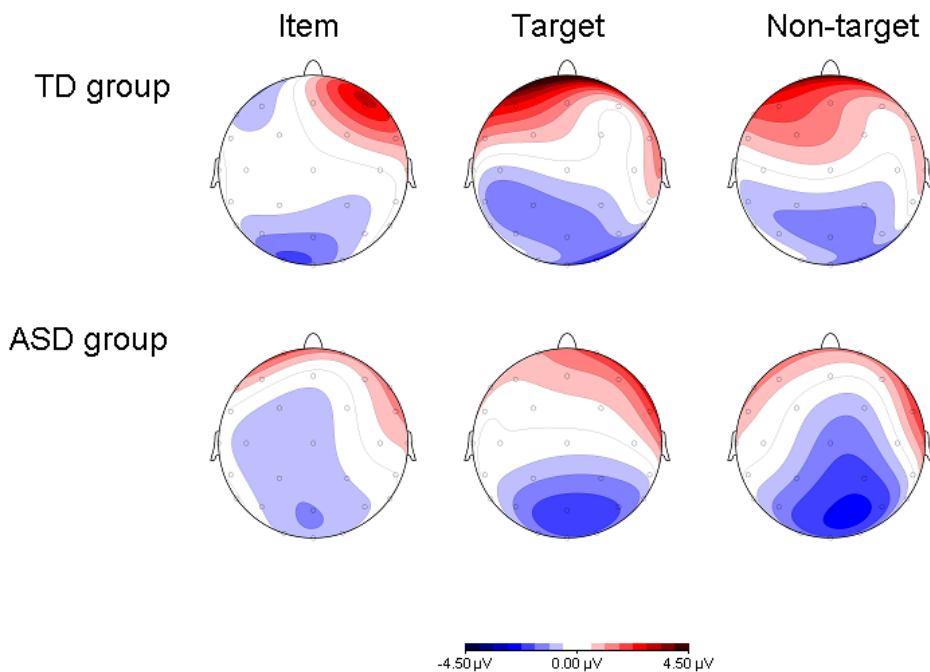
Figure 7.5: 2D scalp distributions of Item, Target and Non-target Old-New ERP amplitude differences (Old minus New words) from 950-1200 ms for TD (N = 18) and ASD (N = 15) groups for Experiment 5.

ERP Analysis

Greenhouse-Geisser corrections are reported where sphericity is violated. The initial analyses were made with within subjects factors of Latency (Early/Late), Task (Item/Target/Non-target), Region (anterior/central/posterior) and Sagittal Plane (left/midline/right) and a between subjects factor of Group. Significant interactions involving Region by Latency, Task, Sagittal plane and/or by Group were further investigated after RMS-z normalization of the ERP amplitudes measurements (McCarthy & Wood, 1985). The mean and standard deviation amplitudes for each region of interest at each time window can be seen in Table 7.3.

			TD (N=18)		ASD (N=15)	
			M	SD	M	SD
300-650 ms	Anterior Left	Item	-0.07	0.62	-0.10	0.56
		Target	-0.33	1.22	0.17	1.11
		Non-target	-0.72	1.12	0.25	1.31
	Anterior Midline	Item	0.47	0.59	0.19	0.70
		Target	0.15	0.94	0.20	1.05
		Non-target	-0.02	1.00	-0.08	1.00
	Anterior Right	Item	0.16	0.73	0.13	0.64
		Target	-0.08	1.02	-0.16	1.01
		Non-target	-0.49	0.94	-0.16	0.89
	Central Left	Item	-0.23	0.47	-0.20	0.41
		Target	-0.39	0.65	0.00	0.82
		Non-target	-0.29	0.51	0.14	0.55
	Central Midline	Item	0.62	0.59	0.21	0.62
		Target	0.55	0.60	0.45	0.66
		Non-target	0.49	0.56	0.11	0.70
	Central Right	Item	-0.16	0.43	0.04	0.44
		Target	0.00	0.79	-0.13	0.69
		Non-target	0.26	0.83	-0.35	0.68
	Posterior Left	Item	-0.25	0.47	-0.14	0.61
		Target	-0.04	1.09	-0.09	0.87
		Non-target	0.24	0.74	0.10	0.69
	Posterior Midline	Item	0.30	0.67	0.09	0.50
		Target	0.48	0.82	0.03	0.78
		Non-target	0.70	0.81	0.11	0.90
	Posterior Right	Item	-0.43	0.86	-0.07	0.72
		Target	0.08	0.76	-0.29	0.89
		Non-target	0.31	0.82	-0.05	0.95
950-1200 ms	Anterior Left	Item	0.37	0.72	0.62	1.07

Region	Condition				
	Target	0.64	1.23	0.52	1.37
	Non-target	0.46	1.38	0.45	1.56
Anterior Midline	Item	0.30	0.62	-0.11	0.53
	Target	0.33	0.95	0.06	0.88
	Non-target	0.37	1.06	-.52	1.15
Anterior Right	Item	0.89	0.98	0.64	1.01
	Target	0.87	0.97	0.43	1.70
	Non-target	0.53	1.25	0.11	1.22
Central Left	Item	-0.10	0.59	-0.27	.67
	Target	0.17	0.87	0.09	1.04
	Non-target	0.24	0.64	0.31	0.80
Central Midline	Item	-0.16	0.58	-054	0.76
	Target	-0.54	0.73	-0.39	0.71
	Non-target	-0.43	0.73	-0.91	0.94
Central Right	Item	0.01	0.48	0.17	0.54
	Target	0.42	0.91	0.15	0.84
	Non-target	0.38	0.96	0.18	0.82
Posterior Left	Item	-0.42	0.57	-0.37	0.61
	Target	-0.69	1.41	-0.14	1.20
	Non-target	-0.48	0.98	0.21	1.08
Posterior Midline	Item	-0.55	0.80	-0.54	0.73
	Target	-1.07	0.76	-0.65	0.94
	Non-target	-0.86	1.06	-0.58	0.74
Posterior Right	Item	-0.60	0.76	-0.03	0.62
	Target	-0.71	0.88	-0.48	0.94
	Non-target	-0.66	1.14	0.10	1.05

Table 7.3: Means and standard deviations for the amplitude differences at each region of interest in the TD and ASD groups for Experiment 5.

As difference values were calculated prior to statistical analysis, significant main effects of Region and/or Latency are a measure of differences in the Old-New effect. A 3 (Task) x 3 (Region) x 3 (Sagittal Plane) x 2 (Latency) x 2 (Group) Repeated Measures ANOVA revealed a main effect of Latency ($F_{(1, 31)} = 104.72$, $p<.01$), which was qualified by a significant Latency x Sagittal Plane interaction ($F_{(2, 62)} = 33.85$, $p<.01$) and Latency x Region x Sagittal Plane interaction ($F_{(3.27, 101.44)} = 4.30$, $p<.01$). The three-way interaction showed that from 300-650 ms the Old-New effect demonstrated a right anterior and midline central positive focus. Right and left hemisphere sites showed negative Old-New amplitude differences. From 950-1200 ms positive Old-New effects were measured at all anterior sites and left and right central sites, whilst negative going Old-New effects were measured at all posterior sites and midline central electrodes. The positivity showed an anterior right focus and the negativity showed a midline

posterior focus.

The Latency x Region interaction was significant (F (1.40, 43.25) = 16.59, p<.01) and differed between groups (Latency x Region x Group interaction F (1.40, 43.25) = 4.69, p<.05). The Task x Latency x Region interaction was significant (F (2.04, 63.29) = 12.58, p<.01), and was qualified by a significant Task x Latency x Region x Group interaction (F (2.04, 63.29) = 3.75, p<.05). This interaction demonstrated that the topography of the early and late Old-New effects differed for the three tasks between groups. To break down the 4-way interaction highlighted by this overall ANOVA, separate analyses were conducted for the early and late Old-New effects separately.

Early Old-New effect (300-650 ms)

The following analysis was conducted to verify the early Old-New effect for both groups and used a 3 Task (Item/Target/ Non-target) x 3 Region (anterior/central/parietal) x 3 Sagittal Plane (left /midline/right) x 2 Group mixed Repeated Measures ANOVA. The results revealed a main effect of Group (F (1, 31) = 5.83, p<.05) where the Old-New difference was larger for TD individuals compared to ASD individuals. Separate analyses for each Group revealed significant positive going Old-New effects for the TD group (main effect of Old-New was significant F (1, 17) = 24.76, p<.01) that did not differ across tasks (main effect of Task was not significant for TD individuals (F (2, 34) = 0.09, p = *n.s.*)). For the ASD group the Old-New effect did not reach significance, see Figure 7.6 (F (1, 14) = 2.13, p = *n.s.*), and was significantly attenuated overall.
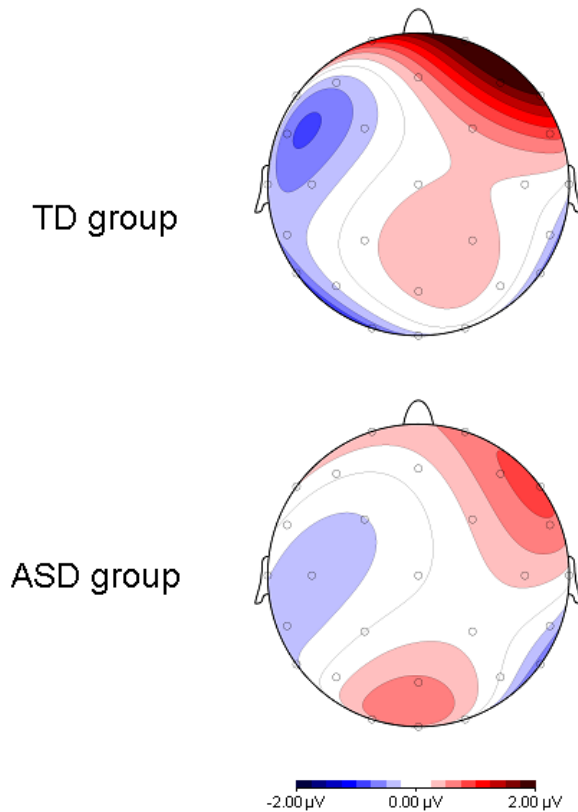
Figure 7.6: Early Old-New effect (300-650 ms) for Item, Target and Non-target trials combined in the TD and ASD groups for Experiment 5.

Late Old-New effect (950-1200 ms)

The late Old-New effect was investigated with a 3 Task (Item/Target/ Non-target) x 3 Region (anterior/central/parietal) x 3 Sagittal Plane (left /midline/right) x 2 Group mixed Repeated Measures ANOVA. The main effect of task was not significant ($F_{(2, 62)} = 1.35$, p = *n.s.*). There was a Region x Group interaction ($F_{(1.52, 47.16)} = 4.80$, p<.05). Separate ANOVAs for each region showed that the TD group demonstrated significantly more positive going anterior Old-New effects ($F_{(1, 31)} = 4.14$, p = .05) and significantly more negative going posterior Old-New effects ($F_{(1, 31)} = 6.77$, p<.05) compared to the ASD group, following the pattern of attenuated Old-New effects in ASD observed in Experiments 1 & 3. There was no difference in the amplitude of the Old-New effect at central regions between groups ($F_{(1, 31)} = 1.19$, p = *n.s.*).

Posterior Old-New effect

To enable comparisons with previous findings of posterior negativity for Target and Non-target judgements (Cycowicz et al., 2001), the posterior electrode cluster was entered into a 3

Task (Item/Target/ Non-target) x 3 Sagittal Plane (left /midline/right) x 2 Latency (Early/Late) x 2 Group mixed Repeated Measures ANOVA. There was a main effect of Latency (F (1, 31) = 39.30, p<.01) where more negative posterior amplitudes were measured from 950-1200 ms. This was qualified by a significant Latency x Group interaction (F (1, 31) = 11.79, p<.01) and Latency x Task x Group interaction (F (1.31, 40.57) = 3.72, p = 0.05). Furthermore when the analysis was repeated for each task separately, significant Latency x Group interactions, for Non-targets (F(1, 31) = 10.50, p<.01) and Targets (F (1, 31) = 8.60, p<.01) were observed. The Latency x Group interaction was not significant during the Item recognition task (F (1, 31) = 0.37, p = *n.s.*) showing that for Item recognition, posterior region amplitudes were comparable between groups at each latency. The analysis replicates previous findings in TD individuals of enhanced late posterior negativity for trials in which contextual colour information is successfully recalled (Cycowicz et al., 2001). The data demonstrated that for the ASD group, posterior negativity during contextual retrieval was comparable in both early and late time windows (showed no enhancement).

Anterior Old-New effect

The anterior electrode cluster was entered into a 3 Task (Item/Target/ Non-target) x 3 Sagittal Plane (left /midline/right) x 2 Latency (Early/Late) x 2 Group mixed Repeated Measures ANOVA. There was a main effect of Latency (F (1, 31) = 14.41, p<.01) which was qualified by a significant Latency x Group interaction (F (1, 31) = 4.00, p = .05). The interaction showed that for TD individuals late anterior Old-New effects were significantly more positive going than early anterior Old-New effects (main effect of Latency was significant F(1, 17) = 10.57, p<.01), however the main effect of Latency was not significant in the ASD group (F(1, 14) = 1.71, p = *n.s.*).

Summary of ERP data

To summarise, TD individuals demonstrated an early widespread Old-New effect for all three tasks. The early Old-New effect was attenuated in the ASD group. TD individuals also demonstrated a late negative posterior Old-New effect and anterior positivity from 950-1200 ms for Item, Target and Non-target recognition. For the TD group, posterior negativity was enhanced during Target and Non-target recognition. The posterior negativity and anterior positivity were present in the ASD group from 950-1200 ms, however they were also present during an earlier time window, from 300-650 ms. The data demonstrate that (unlike the case for TD individuals), Old-New effects were not specific to one time window in individuals with ASD. The results are summarised in Table 7.4.

a) Semantic Memory Old-New effects

	ASD (N=15)	TD (N=18)
SEMANTIC MEMORY		
Early Widespread Positivity (300-650 ms)	X	✓

b) Episodic Memory Old-New effects

	ASD (N=15)		TD (N=18)	
	300-650 ms	950-1200 ms	300-650 ms	950-1200 ms
EPISODIC MEMORY				
Anterior Positivity	✓	✓	X	✓
Posterior Negativity	✓	✓	X	✓

Table 7.4 (a) Summary of findings for Semantic Memory Old-New effects from Experiment 5, and (b) Summary of findings for episodic Memory Old-New effects from Experiment 5. In the TD group Old-New effects were specific to the late time window. In the ASD group, the Old-New effects were present during both time windows.

X = Old-New effect not present, ✓ = Old-New effect present.

7.1.4 Discussion

The behavioural data in this experiment demonstrate that both groups found the Target and Non-target recognition tests more difficult than the Item recognition test. It was predicted that only Target and Non-target recognition test that probe episodic memory would be diminished in the ASD group compared to TD individuals (Bowler et al., 2000a, b, 2007; Tanweer et al., 2010), with preserved Item recognition memory that is thought to be supported by semantic memory. Although marginally diminished Item, Target and Non-target recognition was observed, suggesting that the ASD group found all three tasks more difficult than the TD group, it is worth noting that the numerical differences in each task followed the expected pattern. That is, proportionally, the differences between groups were largest for the Target items followed by the Non-Target items followed by the Item condition. It is possible to speculate that, in this instance, because the task instructions were to memorise study items along with their presentation colour, even the Item task captured aspects of episodic memory (i.e., a multi-feature, colour *plus* item representation of the past, Schacter & Tulving, 1994) for which the ASD group demonstrated diminished performance (this is discussed below).

The present findings confirm existing findings of early positive Old-New effects during Item, Target and Non-target recognition for TD individuals (Cycowicz et al., 2001), and demonstrate that this effect was absent for ASD individuals. These findings replicate earlier

findings of diminished Old-New effects in ASD (Experiment 1 and 3), suggesting that recognition memory judgements are performed using different functional neurophysiology in this group. In line with previous findings (Cycowicz et al., 2001) TD individuals' Target and Non-target recognition showed a late posterior (950-1200 ms) negative Old-New effect associated with the recollection of contextual information. The posterior negativity was not latency-specific for the ASD group; that is to say, it was also present in the earlier time window (300-650 ms) and on trials in which the presentation colour of the image was not recalled. This is evidenced by the absence of any significant interaction with Task and/or Latency for this ERP effect. These findings provide evidence to suggest that the later Old-New effects observed for Target and Non-target recognition, engage the same neural generators for both ASD and TD individuals.

Late anterior positivity for TD individuals has been associated with episodic recollection (see Wolk et al., 2009; Squire & Knowlton, 2000) and it has been suggested that a contribution from anterior regions is not required for decisions based on semantic memory alone (Cycowicz et al., 2001). In the current study, and in line with previous findings reported above, anterior positivity was observed in the TD group and was enhanced from 950-1200 ms compared to 300-650 ms. The amplitude of the effect was not enhanced in the later time window in the ASD group. The non-specific latency of the effect in the ASD group found here, may impact upon the phenomenological experience of episodic remembering in this population. Furthermore, this difference may be associated with less episodic and more semantic judgements observed in ASD compared to TD individuals (see Tanweer et al., 2010; Bowler et al., 2007).

The observation of equal early Old-New effects for Item, Target and Non-target recognition in the TD group is in line with Cycowicz et al. (2001) and suggests that early Old-New effects did not differ between trials in which context information was required and trials in which it was not. Cycowicz and colleagues have interpreted this ERP effect as a correlate of semantic memory and this interpretation is consistent with the findings observed in this experiment. This does not imply that (at least on some trials) episodic recollection was not experienced for a correctly identified studied image during the Item memory task. For example, Paivio (1986) suggests that picture stimuli, by contrast with word stimuli, engender robust Old-New effects as they can be encoded both perceptually and semantically. In addition, Nelson (1979) argues that picture stimuli are remarkably resistant to forgetting, as they have distinct sensory codes, suggesting that episodic recollection may be more common for pictures than for other types of stimuli.

The task demands in the present experiment were for participants to memorise the picture along with the colour it was presented in (an emphasis was placed on both pieces of information). It is therefore possible that the picture stimuli used for the current experiment were

occasionally accompanied by episodic recollection within the Item memory trials. The early Old-New effect found here appears remarkably similar (slightly earlier but overlapping temporal window) to the parietal Old-New effects reported in previous recognition memory studies for episodic remembering (~400-800 ms, Wilding & Rugg, 1996, 1997; Senkfor & Van Petten, 1998; Trott, Friedman, Ritter, Fabiani & Snodgrass, 1999; see Rugg & Curran, 2007 for a review) suggests that this ERP effect may have included a contribution from recollective responses (at least on some trials). This ERP was diminished in the ASD group, an observation that resonates with the episodic memory difficulties observed in this population (Bowler et al., 2007) and with the marginally diminished Item recognition performance for ASD individuals observed in the current experiment.

Diminished behavioural recognition memory performance in ASD was accompanied by three temporally and topographically distinct ERPs. First, the early (300-650 ms) Old-New effect that was observed for the TD group was absent for ASD individuals. Second, a late posterior negativity was observed in both groups from 950-1200 ms. For TD individuals, this effect was enhanced during contextual retrieval (for Targets and Non-targets) compared to Item recognition, however, was equivalent during Item and Context recognition for the ASD group. Furthermore this posterior negativity was not specific to this time-window in the ASD group; who also demonstrated posterior negativity from 300-650 ms. Third, a late anterior positivity was observed for TD individuals for Items, Targets and Non-targets and was also present for the ASD group. The anterior positivity was enhanced in the TD group from 950-1200 ms compared to 300-650 ms, but again, this effect did not differ by latency interval in the ASD group. These findings provide evidence to show that Old-New effects for nameable line-drawings are diminished in ASD and provide support for the findings in Experiments 1 and 3. In addition these results suggest that it is not only verbal stimuli that are associated with diminished Old-New effects in ASD, but also nameable pictorial stimuli.

To sum up, in the present experiment, whilst the TD group showed a specific posterior Old-New negativity from 950-1200 ms for Target and Non-target recognition, the corresponding ERPs were not enhanced for Targets and Non-targets nor were they specific to this time window in the ASD group. Furthermore, these Old-New effects occurred alongside an anterior positivity that was also diminished in ASD across all three types of recognition trial. The findings demonstrate first that ASD individuals engage less functional neural activity to aid recognition, second, that Target and Non-target recognition are accompanied by a diminished and non-specific posterior negativity in the ASD group, and third, that late anterior positivity, associated with episodic recollection (see Wolk et al., 2009; Squire & Knowlton, 2000) in TD, is diminished for ASD individuals. Furthermore, these ERP data show that although episodic memory was marginally behaviourally diminished, the topographical patterning of Old-New effects is similar in both participant groups, suggesting that the quality and phenomenological experience of episodic

Remembering is similar. This echoes the findings of behavioural manipulations on Remembering and Knowing in ASD reported by Bowler et al. (2007) and the ERP findings of earlier experiments. Lastly, the absent early Old-New effect in ASD supports the findings from previous experiments by highlighting abnormalities in a time window associated with semantic memory in TD individuals. This finding is in line with the findings from Experiments 1, 3 & 4 in suggesting that there are atypicalities in the neural correlates of semantic memory in ASD.

Chapter 8 : GENERAL DISCUSSION

8.1 Summary of Empirical Chapters

The current research aimed to build upon existing behavioural research, by linking the memory profile of individuals with ASD to electrophysiological activity in different cortical regions of the brain. The ultimate aim of the research was to refine models of memory in ASD and elucidate similarities and differences between memory in ASD and that of TD individuals. A series of five experiments were carried out. In total, 86 individuals with ASD were tested (including 15 females). The mean FIQ and VIQ were 110 and mean age was 35.5 years. The ASD individuals were matched to 82 TD individuals (including 12 females) on VIQ and FIQ (the corresponding values were 110 and 109 respectively) and had a mean age of 36.51 years. A summary of participant characteristics for each experiment, together with the behavioural and/or electrophysiological findings are summarised in Table 8.1.

	Group	Participants	Methods	Task Procedure	Stimuli	Behavioural Findings	ERP Findings	Conclusions	Questions
Exp. 1	22 ASD 14 TD	VIQ = 106 PIQ= 99 FIQ = 103 Age = 25 yrs	Behaviour & ERP	Old/New Recognition Task	Words	No group differences in overall recognition	Attenuated Old-New effect for ASD group post 800ms compared to TD group Topographical differences in the Old-New effect (diminished in ASD) from 300-500ms	Different cognitive processes engaged by ASD individuals to aid recognition, despite comparable overall recognition memory performance	Is episodic and semantic memory qualitatively similar in ASD? Next – use the Remember /Know test.
Exp. 2	23 ASD 22 TD	VIQ = 109 PIQ = 106 FIQ = 108 Age = 40 yrs	Behaviour	Old/New & Remember/Know Judgement	Words	No group differences in overall recognition Diminished episodic Memory & preserved semantic Memory in ASD compared to TD individuals.		ASD group engage episodic Remembering less often than TD individuals. This was observed alongside preserved semantic recognition.	What about neuro-physiological evidence to investigate the qualitative similarities between Remember and Know judgements? Next – to investigate Remember/ Know ERP Old-New effects in ASD

	Group	Participants	Methods	Task Procedure	Stimuli	Behavioural Findings	ERP Findings	Conclusions	Questions
Exp. 3	14 ASD 16 TD	VIQ = 114 PIQ = 112 FIQ = 114 Age = 38 yrs	Behaviour & ERP	Old/New & Remember/ Know Judgement	Words	No group differences in overall recognition No group differences in susceptibility to memory illusions	Episodic Remember Old-New effects for True and False recognition were not significantly different between groups. Know Old-New effects showed anterior negativity from 800-950ms in the ASD group, which was absent for TD individuals.	Episodic Remembering appears to have qualitatively similar electro-physiological correlates in ASD compared to TD individuals. Semantic Know judgements are associated with a different functional neurophysiology in the ASD group which offsets diminished episodic memory, or, may give rise to diminished episodic memory in ASD.	What about stimuli that are non-nameable and do not hold any contextual information or pre-existing verbal information? Next - investigate Remember and Know Old-New effects for non-nameable and novel Kaleidoscope images.

	Group Sizes	Participants	Method	Task Procedure	Stimuli	Behavioural Findings	ERP Findings	Conclusions	Questions
Exp. 4	12 ASD 12 TD	VIQ = 111 PIQ = 109 FIQ = 111 Age = 40 yrs	Behaviour & ERP	Remember/ Know/ New Judgement	Non-nameable Kaleido-scope Images	No group differences in overall recognition Diminished episodic Memory & preserved semantic Memory in ASD compared to TD individuals	Remember Old-New effects demonstrated topographical similarities between groups (anterior focus and accompanying posterior positivity). Know Old-New effects demonstrated topographical similarities from 300-500ms but marginal differences from 500-700ms (posterior activity in the ASD group compared to anterior in TD group) Old-New effects were enhanced in the ASD group.	Episodic memory appears qualitatively similar in ASD (topographically similar to TD). Semantic memory shows marginal qualitative differences in topography. Remember and Know Old-New effects are enhanced in ASD for kaleidoscope stimuli. Perhaps this is due to the enhanced propensity to reject New images on perceptual grounds. Alternatively, these results suggest TD individuals attach labels to stimuli to aid recognition. As labelling was not a strategy that was afforded by this set of stimuli, the TD group showed diminished Old-New effects relative to ASD individuals.	Are diminished Old-New effects in ASD specific to nameable stimuli (words), or are there deficits when recognising nameable images? Are the diminished Old-New effects confined to the Remember/ Know paradigm, or can differences be observed using other task procedures? Next – investigate Old-New effects for semantic and episodic memory using the Inclusion/ Exclusion paradigm with nameable line drawings.

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	Group Sizes	Participants	Methods	Task Procedure	Stimuli	Behaviour Findings	ERP Findings	Conclusions	Questions
Exp. 5	15 ASD 18 TD	VIQ = 113 PIQ = 110 FIQ = 112 Age = 38 yrs	Behaviour & ERP	Old/New & Target/ Other Judgement	Nameable Line Drawings	Both groups found Target and Non-target recognition more difficult than Item recognition The ASD group was marginally worse across all three types of recognition compared to the TD group	TD individuals demonstrated early (300-650 ms) positive Old-New effects for all correctly recognised drawings, this was absent in the ASD group. TD individuals demonstrated an enhanced late (950-1200 ms) posterior negativity for Target and Non-target recognition. This posterior negativity was not specific to the later time window in the ASD group (it was also present from 300-650 ms). TD individuals demonstrated enhanced anterior positivity from 950-1200, which was non-specific to this time window in the ASD group (it was also present from 300-650 ms).	Early recognition Old-New effects observed for TD individuals were absent in the ASD group, suggesting that different cognitive processes were engaged during Item, Target and Non-target recognition in ASD. The enhanced posterior negativity for TD individuals from 950-1200 ms (during Target and Non-target recognition) was not enhanced in the ASD group suggesting that ERP Old-New effects associated with contextual retrieval in TD are attenuated in ASD. Late anterior positivity associated with episodic recollection in TD was also attenuated in ASD. The results suggest differences in episodic and semantic memory in ASD.	Is the diminished Old-New effect specific to nameable stimuli? Does the diminished ERP Old-New effect show differences earlier than at recognition – what about at encoding (i.e., subsequent memory effects)?

Table 8.1: Summary table of the behavioural and electrophysiological findings from Experiments 1 to 5.

Experiment 1 was the first of its kind to consider recognition memory ERPs in adults with ASD, with the aim to elucidate the underlying neural processes driving preserved behavioural recognition performance in this group. Both groups showed a recognition advantage for low frequency words, replicating current findings for TD individuals (Guttentag & Caroll, 1994) and individuals with ASD (Bowler et al., 2000a). Positive ERP Old-New word effects were present in both groups; however the duration and topography of the effect differed for ASD individuals. Consistent with the current literature (Rugg and Curran, 2007), Old-New effects for TD individuals were characterised by three temporally and topographically distinct components, (1) an early (300-500 ms) anterior focused Old-New effect associated with semantic memory, (2) a later (400-800 ms) parietal focused Old-New effect associated with episodic memory, and (3) a late (800-1700 ms) right and midline anterior and anterior- temporal Old-New effect associated with episodic memory. Differences in the Old-New effect for ASD individuals were observed from 300-500 ms where the Old-New effect demonstrated anterior focus in the TD group, whilst the effect had a left posterior focus for the ASD group. From 400-800 ms both groups showed a similar parietal Old-New effect, but Old-New word effects were shorter-lasting in the ASD group, ending at approximately 800 ms rather than until the end of the recording epoch (1700 ms) with a right and midline anterior and anterior-temporal focus, as in the TD group.

The word frequency manipulation check supported the conjecture that behavioural recognition in both groups was completed using similar processes and that comparable behavioural performance masked underlying ERP differences in the Old-New effect for individuals with ASD. The findings suggest that recognition results from different underlying neural activity in each group. For TD individuals, recognition engages at least two distinct memory systems as indicated by the topographically and temporally distinct activity of the Old-New effect, which shows anterior and parietal/ posterior foci. This contrasts with only parietal/posterior focused Old-New effects for the ASD group, suggesting that recognition memory may engage only a single memory system in these individuals. Earlier behavioural observations led to the hypothesis that recognition is less reliant upon the episodic memory system and more reliant upon semantic memory in ASD (Bowler et al., 2000a, b, 2007). However, this explanation is not entirely consistent with the results of Experiment 1. Semantic Know (mid frontal) Old-New effects were absent for the ASD group in the current experiment, whilst activity associated with episodic memory (left parietal/posterior topography) seemed relatively preserved. If the ASD group were using processes less reliant upon episodic memory and more reliant upon semantic memory, diminished parietal/posterior Old-New effects and increased mid-frontal Old-New effects would be expected. Since both groups demonstrated preserved parietal Old-New effects from 400-800 ms, the qualitative experience of episodic Remember judgements is likely to be preserved despite quantitatively diminished reports.

Experiment 2 replicated findings from Bowler et al., (2000a) by demonstrating quantitatively diminished episodic Remember judgements and increased semantic Know judgements alongside preserved overall recognition memory performance in ASD. Enhanced recognition for low frequency words over high frequency words was again observed in both groups (consistent with Guttentag & Carroll, 1994; Bowler et al., 2000a and Experiment 1). Importantly the word Frequency manipulation interacted with Remember and Know judgements similarly in groups; both were more likely to Remember low frequency words and Know high frequency words (Gardiner & Java, 1990; Gardiner, Richardson-Klavehn & Ramponi, 1997). These findings provide further evidence for qualitative similarities in recognition memory in ASD and are important for discussing the findings from Experiment 3 which included a largely overlapping sample of participants.

Experiment 3 was the first ever study to consider the mid frontal Old-New effect for Know judgements (300-500 ms) and the parietal Old-New effect for Remember judgements (400-800 ms) in ASD. The attenuated recognition ERP Old-New effect for ASD individuals reported in Experiment 1 was investigated further to elucidate whether the diminished effect (post 800 ms) stemmed from diminished Remember, Know or both types of judgement. The behavioural data replicated previous findings, showing that individuals with ASD are susceptible to memory illusions (Bowler et al., 2000b; Kamio & Toichi, 2007), but whilst it was expected that Remember responses would be diminished in the ASD group (as in Experiment 2), this was not replicated here (possible reasons for which are discussed on p.94).

The ERP data from Experiment 3 replicated diminished Old-New effects in ASD (Experiment 1), and extended this finding to associatively related, non-presented word stimuli. Remember judgement ERPs were present in both groups and showed a parietal-occipital focus, in line with current literature for TD individuals (Rugg & Curran, 2007). The findings provide support for the suggestion that individuals with ASD have similar qualitative experiences of Remembering compared to TD individuals. They report similar experiences accompanying Remember judgements as the comparison participants (see Appendix 1) and show similar topographical Remember Old-New effects. This suggests that episodic Remember judgements are labelled accurately but occur less often for individuals with ASD (see Bowler et al., 2007). The ERP data also suggest that a similar phenomenological experience of autonoetic conscious awareness accompanied both True and False recognition in both groups.

Know ERPs showed no group differences from 300-500 ms, however a late occurring (800-950 ms) anterior negativity was observed for these judgements in the ASD group. This suggests that Know judgements were performed using different functional neurophysiological

processes in this population, thus supporting the observation of Experiment 1. One suggestion for this finding is that at least some trials, semantic Know judgements may require a more elaborative process in ASD. It may also be the case that individuals with ASD experience some typical Remember and Know experiences, however also experience a third, distorted type of experience that is neither semantic nor episodic which they mislabel as 'Know' experiences. These may include a number of residual muddled or garbled 'Remember' or 'Know' responses which contribute to the behavioural and neurophysiological findings observed in this thesis. This happens to alter the Remember/Know proportions in behavioural tests, and would account for preserved Know judgements in ASD measured at a behavioural level, being associated with atypical ERP Old-New effects during retrieval. These speculations would need to be tested with an appropriate methodology, for example, (following the Old/New response) the inclusion of a third response option; Remember, Know or *Neither*, (or fourth; Remember, Know, Neither or *Guess*). If this hypothesis were to be supported, results from studies such as these would be expected to reveal typical Remember and Know judgement ERPs in ASD, but atypical ERPs for 'Neither' or 'Guess' responses.

As well as experiencing difficulties with episodically-defined multi-feature representations, there is evidence to suggest that individuals with ASD experience difficulties relating visual-perceptual (e.g., visual illusions, Happé, 1996), and conceptual (e.g., language, Happé, 1997) stimuli within context. As words hold pre-existing context and meaning for participants prior to the study episode, it is possible that the difficulties with relating words within context for this population, accounts for the differences observed in the recognition Old-New effects for words in Experiments 1 and 3. ERP evidence also suggests that individuals with ASD perform significantly worse in tasks that require linguistic and language related processing compared to tasks that are non-verbal, indexed by reduced N400 amplitudes in ASD for verbal stimuli (word pairs) and typical N400 amplitudes in non-verbal tasks (McCleery et al., 2009; Strandburg et al., 1993, also see p.117). To address these issues, Experiment 4 used novel, meaningless and non-nameable kaleidoscope images in a Remember/Know paradigm to investigate whether reduced Old-New effects in ASD extend to stimuli that are difficult to verbalise.

The behavioural results of Experiment 4 replicated previous findings of diminished episodic Remember judgements and preserved semantic Know judgements in ASD (Experiment 2; Bowler et al., 2000a, b, 2007). The ERP data showed that the topography of Remember ERPs from 400-800 ms were again comparable between groups, as were Know Old-New effects from 300-500 ms (replicating findings from Experiment 3). However, similar to the late occurring differences in Know ERP Old-New effects observed in Experiment 3, Know ERPs also differed marginally in this experiment from 500-700 ms. More specifically, Know Old-New effects retained an anterior focus in the TD group but for ASD individuals showed a posterior positivity, much like

the Remember Old-New effects observed for both groups. This mirrors the findings from Experiment 3 and strongly suggests that different functional neurophysiological processes were operating in the ASD group. Importantly, the present finding demonstrated no diminished Old-New effect in the ASD group. On the contrary, both Remember and Know Old-New ERP effects showed enhanced amplitudes in the ASD group. These results suggest that for Experiments 1 and 3, where the TD group showed larger Old-New effects compared to the ASD group, the TD group may have completed the task using verbal strategies to support recognition. In Experiment 4, this was a strategy not readily afforded by the stimuli and may have contributed to the attenuated Old-New effects that were observed in the TD group.

Experiment 5 used a convergent approach, the Inclusion/Exclusion paradigm (see p.64 for methodological details). This was important in order not to base the conclusions of the current research upon a single methodological Remember/Know paradigm. Coloured line-drawings of common nameable images were used for this experiment (from Cycowicz et al., 2001). The behavioural data revealed a marginally diminished behavioural recognition performance in the ASD group. Replicating Cycowicz et al. (2001), TD individuals demonstrated early Old-New effects for all recognised stimuli regardless of whether the presentation colour of the stimulus was recalled. This ERP Old-New effect was absent in the ASD group, which provides further evidence to suggest differences in the operation of the semantic memory system in ASD, and furthermore suggests that some aspect of the quality of Remember judgements may not be preserved. TD individuals demonstrated an enhanced late posterior negativity for trials in which context was successfully recalled, which is again in line with previous findings (Cycowicz et al., 2001). However the ASD group demonstrated comparable amplitudes for all stimuli and time windows. A simultaneous late anterior positivity, associated with episodic recollection was observed in both groups for all trials, but was significantly larger for TD individuals.

Both groups demonstrated late Old-New effects for trials in which contextual information from the study phase was successfully recalled; however, the amplitude of this effect was significantly diminished in ASD compared to matched TD individuals. Moreover, the onset of this Old-New effect was observed much earlier in the ASD group compared to the TD group suggesting that the temporal patterning of episodic ERP Old-New effect differs between the two samples (see Figure 4.2 for topographical scalp maps from Experiment 1 and Figure 5.8 for topographical scalp maps from Experiment 3). Furthermore, an early ERP Old-New effect associated with semantic memory judgements in TD, was absent for the ASD group. To summarise, in view of the comparable topography but diminished amplitudes of episodic ERP Old-New effects, it is hypothesised that the difference in episodic memory is quantitative rather than qualitative in nature. On the other hand, as the topographical patterning of semantic ERP Old-New effects differed between groups, the group differences in semantic memory appear to

be qualitative rather than quantitative in nature.

8.2 Main Conclusions

Overall, with minor exceptions, the findings in this thesis confirmed the undiminished recognition memory performance, together with diminished episodic Remembering in ASD. Furthermore, the empirical work reported here has also shown that recognition memory Old-New ERP effects are diminished in ASD. The atypical Old-New effect appears rather unexpectedly, to result from atypical Know rather than from atypical Remember responses. The main conclusions from this research are that;

(1) Individuals with ASD like TD individuals, show ERP Old-New effects for previously studied stimuli.

(2) Word recognition ERP Old-New effects are diminished in ASD from 800-950 ms stimulus-onset compared to TD individuals.

(3) Episodic memory, although quantitatively diminished when measured behaviourally, on the basis of ERP evidence, does not appear to be qualitatively different in ASD.

(4) Preserved behavioural indices of semantic memory functioning in ASD is associated with different underlying neurophysiological processes as evidenced in ERP patterns.

(5) Susceptibility to illusory memories is preserved at a behavioural level in ASD. Illusory stimuli Old-New effects are attenuated post 800ms in ASD.

(6) Although ERP Old-New effects are diminished for individuals with ASD for verbal material, this is not the case when non-nameable and novel kaleidoscope images are studied. The diminished Old-New effect therefore appears to result from difficulties with processing stimuli that have a verbal component (whether they are words or nameable pictures).

(7) Convergent evidence using the Inclusion/Exclusion paradigm suggests Old-New effects are also diminished for nameable (line-drawing) stimuli. This finding suggests that verbal stimuli engender a diminution of the Old-New effect (similar to that seen in Remember/Know studies of word memory), and adding verbal labels to stimuli diminishes the Old-New effect in ASD (possible ways to test this hypothesis are explored in section 8.4).

Diminished episodic memory in ASD is clearly compensated by an increase in semantic memory; however the residual episodic memory appears to be qualitatively similar between groups (Experiment 3 and 4). That is, individuals with ASD appear to be capable of having similar phenomenological experiences of episodic Remembering and autonoetic conscious awareness as TD individuals, even if they do so less often. There is clear evidence to suggest that behaviourally, the semantic memory system is largely intact for high functioning individuals with ASD (Boucher & Mayes, *in press*) however, the evidence presented in this thesis further suggests that these judgements rely on different functional neuropsychological processes. This was demonstrated by temporal and topographical differences within semantic Know Old-New effects in ASD. Given that participants were only able to give a Remember or Know response, one possibility for the results observed here, is that individuals with ASD were having to give Know responses to stimuli that were not Remembered (i.e., Know responses comparable to TD individuals *plus* a different kind of judgement). Another possibility is that Know judgements in ASD are different from those made by TD individuals. The question is whether it is the former or the latter explanation that is operating for semantic Know judgements in ASD. Experimental manipulations that have been shown to affect Know and Remember judgements in TD and ASD individuals could be used to elucidate this. For example, Old-New ERP effects could be investigated under manipulations such as a Study/Test modality shift (auditory versus written), which selectively diminishes Know responses but leaves Remember responses preserved. Alternatively a 'full' versus 'divided'[6] attention manipulation at study, would be expected to diminish Remember responses but leave Know responses unchanged (see Bowler et al., 2007 for examples of possible manipulations). The ERPs gathered from studies such as these would inform models of memory in ASD by elucidating whether these manipulations affect Remember and Know judgement ERPs similarly in both groups. If these manipulations were found to impact Know ERPs similarly across groups, it would provide robust evidence to suggest that these judgements were qualitatively similar, however a difference would imply that TD and ASD individuals use different strategies to complete the task (i.e., that Know judgements differ between groups). Knowledge gathered from these types of studies would clarify whether Know judgements are, in part, similar to responses made by TD individuals, or whether they are a different kind of judgment altogether.

In Experiment 3, the ASD group demonstrated a late anterior negativity (800-950 ms) associated with semantic Know judgments, which was not observed in the TD group, however mid-frontal Old-New effects (300-500 ms) for Know judgements and parietal Old-New effects (400-800 ms) for Remember judgements demonstrated a similar topography between groups for

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[6] For the divided attention condition, the participant receives a simultaneous instruction to label sounds as 'high', 'medium' or 'low' pitch.

studied and illusory word stimuli. This finding suggests that similar cognitive processes were engaged for the earlier time windows in both groups and is consistent with behavioural evidence for spared illusory memories in ASD (Bowler et al., 2000b and Experiment 3).

The findings from Experiment 4 provide evidence that the late anterior negativity observed in Experiment 3 may be specific to word stimuli, as it was not observed when novel kaleidoscope images were studied. Rather the results from Experiment 4 show that Know Old-New effects engaged more posterior activity in the ASD group from 500-700 ms compared to TD individuals. Posterior activity was only observed (with accompanying anterior positivity) for Remember ERP Old-New effects in the TD group, whilst it was observed for <u>both</u> Remember and Know ERP Old-New effects in the ASD group. These results show that retrieval in ASD may engage a single memory system (the topography of both Remember and Know judgement Old-New effects were similar) whilst for TD individuals two memory systems may operate (Know judgements engaged less posterior activity than Remember judgements in TD individuals). Furthermore, the absence of an ERP difference in episodic memory topography between groups implies that the nature of the difference in this domain of memory is quantitative in nature rather than qualitative.

The research presented in this thesis suggests that the diminished Old-New effect in ASD (Experiments 1, 3 and 5), may result from an impaired ability to use verbal labels for words or for picture stimuli to aid recognition. Word stimuli can be supported by context (for example, by placing the word within a linguistic context), and picture stimuli too, can be placed within context (for example, participants can create imagined visual scenes, or use a verbal/ language based strategy by naming the line drawings to support their memory). Kaleidoscope images are however, nameable only with great difficulty. The novelty of the images makes them hard to place within a meaningful visual scene. In this case, verbal labels or imagery are much less likely to be used to support recognition and it is only for this last class of stimuli that individuals with ASD show an enhanced ERP Old-New effect compared to TD individuals. One suggestion is that the enhancement of the effect may be a result of increased ability to reject new pictures on perceptual grounds for ASD individuals compared to the TD group (resulting in larger Old-New effects for the ASD group). Alternatively these results may demonstrate that individuals with ASD benefit more than the TD group from the specific nature of these stimuli. For example, they may have engaged in enhanced or more elaborate memory processes due to the possibility for detail focus inherent in the images (Happé & Frith, 2006). It is also possible that the TD group experienced greater difficulty in memorising these stimuli because these stimuli did not afford verbal labelling (this point is discussed further in section 8.4).

8.3 What is the Extent of Diminished Episodic Memory in ASD?

The evidence from Experiments 2 and 4 provide support for previous findings of quantitatively diminished episodic Remember judgements in ASD. Alongside these findings, Experiments 3 and 4 suggest that episodic memory judgements made by individuals with ASD are in large-part qualitatively similar to those made by TD individuals. This is demonstrated by a similar scalp topography for these Old-New effects in both groups. The results from Experiment 5 extend this finding and reveal that late Old-New effects associated with the retrieval of contextual information in the TD group, were not specific to this time window in the ASD group (the pattern of activity was also observed from 300-650ms). This evidence suggests that there may also be differences in the functioning of the episodic memory system in people with ASD.

The absence of between-group differences in episodic memory ERP Old-New effects for Remember judgements in Experiments 3 and 4, and the diminished early Old-New effects in the ASD group present for both semantic and episodic memory judgements in the TD group, in Experiment 5, all suggest that although later ERP components associated with episodic memory are intact for individuals with ASD, earlier components may be attenuated. It could be argued that recognition judgements during Experiment 5 were more difficult than during Experiment 3 as the study phase instructions differed between the two tasks. For example, the study-phase instructions for the Inclusion/Exclusion paradigm require participants to recall a feature of that item (i.e. colour) that is essential for a successful Target or Non-target judgment. Individuals with ASD may show impaired performance during tasks that require the simultaneous learning of items (line drawings) and their context (colour of presentation). Therefore, tasks where both item and context are specified/ presented during the study phase may be more difficult for individuals with ASD compared to when successful episodic Remember judgements can also include other and idiosyncratic experiences from the study phase.

The extent of the episodic memory impairment in ASD could be further studied by recording ERPs during encoding. Subsequently Remembered pictures have been associated with distinct memory processes during encoding compared to those subsequently Known (Duarte et al., 2004), whereby Remembered items are associated with early right lateralised anterior activity followed by bilateral positivity whilst subsequently Known items are associated with early left lateralised anterior positivity. Studies that record ERPs during encoding would elucidate whether items which are presented within a to-be-remembered context present a particular difficulty for individuals with ASD compared to items presented where the to-be-remembered context is not specified.

In sum, the evidence presented here suggests the diminished Old-New effect reported in Experiment 1 and 3 appears not to be a result of atypical Remember-related ERPs, but rather

atypical Know-related ERPs. This pattern of findings was observed across a range of test paradigms. Why this occurred is an important issue and will be discussed after the other main findings have been explored.

8.4 Are there Processing Difficulties in ASD related to Verbal Mediation?

The next section of this thesis discusses how the present findings can be interpreted in relation to the development of inner speech in TD and ASD. There is now a substantial body of research that has highlighted links between individuals with ASD and those with language impairment. Specific Language Impairment (SLI), is diagnosed in children who display significantly impaired spoken language functioning (at least 1.25 SDs below the mean) accompanied by normal non-verbal IQ with no sensory or neurological dysfunction. There are several subtypes of SLI including expressive language disorder (where comprehension is relatively preserved), mixed receptive-expressive language disorder, and phonological disorder (American Psychiatric Association, 2000). It was initially thought that SLI and ASD were related, and that ASD resulted from a language disorder which subsequently leads to social withdrawal (Rutter, 1967). However, Boucher (1976) argued against this hypothesis on the basis that SLI can occur in the absence of ASD, and the observation that social withdrawal is more persistent in individuals with ASD than structural language impairments. Moreover AS is by definition, characterised by the absence of structural language delay or impairment, meaning the idea that ASD results from SLI is unlikely.

Although ASD and SLI are considered to be qualitatively different (Williams, Botting & Boucher, 2008), mixed forms do occur. Research has also suggested that there is a genetic relationship between vulnerability to ASD and vulnerability to language impairments (Szatmari, MacLean, Jones, Bryson, Zwaigenbaum, Bartolucci et al., 2000) which supports the notion of a shared etiological factor between groups. Furthermore the language impairments observed in ASD and SLI have been associated with a similar neurobiology, a pattern of asymmetry reversal in language-related inferior lateral frontal regions (Broca's area), (De Fossé, Hodge, Makris, Kennedy, Caviness, McGrath et al., 2004; for a whole-brain analysis see Herbert, Ziegler, Deutsch, O'Brien, Kennedy, Filipek, 2005). In view of this evidence, it has been suggested that ASD and SLI are closely related, with some small areas of overlap between the language impairment observed in each of the disorders, but that different language impairments predominate in each disorder (Williams et al., 2008).

TD children are thought to regulate their behaviour early on in life using interpersonal dialogues, for example, with a caregiver (also known as 'private speech', Winsler, De Leon, Wallace, Carlton & Willson-Quayle, 2003), which throughout the course of development

becomes intrapersonal (also known as 'inner speech', Winsler & Naglieri, 2003). This ability is thought to enable the individual to regulate their own behaviour in the absence of others. According to Vygotsky (1987), this type of verbal thinking is crucial for flexible cognition and behaviour. Furthermore, Vygotsky argued that the shift from 'private' (i.e., self-directed overt vocalisations) to 'inner' covert speech during middle childhood allows multiple domains of cognition (higher order executive functions such as planning or task switching, and short-term memory tasks such as serial recall) to become verbally mediated (as opposed to visually mediated, see Al-Namlah, Fennyhough & Meins, 2006).

It is well established that TD children from about 7 years of age will recall a sequence of pictorial stimuli better if they do not have a phonologically similar structure (bird, bell, shoe), compared to when the items in the list do (cat, mat, hat), (Hitch, Woodin & Baker, 1989). These findings suggest that inner speech or 'verbal mediation' is employed during short-term memory for visually presented information, because only pictorial stimuli which have been converted from visual to verbal form will be influenced by this type of phonological manipulation (Williams & Jarrold, 2010). This is known as the 'phonological similarity effect' (PSE), and is a robust finding in the literature on TD children (e.g., see Gathercole, Pickering, Hall & Peaker, 2001). Below approximately 7 years of age, children do not show a PSE, but rather tend to recall visually similar items (for example, ruler, pencil, flute, *or*, ball, button, apple) significantly less well than visually dissimilar items (Hitch, Woodin & Baker, 1989). These findings provide evidence to suggest that younger children mediate short-term memory visually, whilst older children (about 7 years of age onwards) mediate their short-term memory verbally. This shift from visual to verbally mediated memory is in line with Vygotsky's theory (1987) and other more recent Vygotskian theorists (Al-Namlah et al., 2006).

One way to test whether aspects of cognition are verbally mediated is to prevent participants from using inner speech by imposing 'articulatory suppression' (repeating a word out loud continuously) during the presentation of studied stimuli (Murray, 1967). If articulatory suppression results in a diminished performance, this would provide evidence to suggest that the task was verbally mediated by the individual. This technique is particularly useful for investigations into the cognitive profile of individuals with ASD, and in tests of EF such as self regulation and cognitive flexibility, individuals with ASD demonstrate impairments which have been associated with diminished use of inner speech in other clinical populations (Hill, 2004a).

Recent research has provided evidence to suggest that performance of individuals with ASD on EF tasks is not significantly negatively affected by manipulations of articulatory suppression. For example in EF tests of task-switching under conditions of articulatory suppression (i.e., constantly repeating a familiar word), Holland and Low (2010), and

Whitehouse, Maybery and Durkin (2006) have found there to be no drop in performance for individuals with ASD compared to TD individuals. Williams, Bowler and Jarrold, (*in press*) and Wallace et al., (2006) have also reported preserved performance for individuals with ASD under articulatory suppression during planning tasks such as the Tower of London puzzle (for a description of this task see p. 19). This manipulation was found to significantly negatively affect performance on the task in the TD group. These results suggest that individuals with ASD may rely less on inner speech to mediate their performance on such tasks. In tests of serial recall Williams, Happé and Jarrold (2008) showed that children with verbal mental ages of 7 and above, with and without a diagnosis of ASD demonstrate a significant PSE of visually presented information in short-term memory. In their study both TD and ASD children with verbal mental ages below 7 years did not show a PSE, but instead a visual similarity effect. These results demonstrate appropriate age-related changes in visual and verbal mediations of serial recall for children with ASD, however taking into account the results from investigations into both EF and serial recall performance in ASD, the findings suggest that these individuals may rely less upon inner speech and use other types of mediation for their performance on such cognitive tasks.

In light of the research into the role of inner speech, it is possible to speculate on the nature of the current Old-New ERP findings. The current findings revealed an unexpected and contrasting pattern of amplitude differences for nameable versus non-nameable stimuli for individuals with ASD. Old-New amplitude differences were diminished in the ASD group when the to-be-memorised stimuli were words or nameable drawings, whilst Old-New effects were enhanced compared to TD individuals when stimuli were non-nameable, non-verbal and novel images. The diminished Old-New effects in the ASD group reported in this thesis may result from a diminished ability to use verbal labels or 'inner speech' (see Winsler & Naglieri, 2003) to support recognition. This would explain why unlike TD individuals, ASD individuals may experience greater difficulty with nameable and verbal, to-be-memorised stimuli. Furthermore, atypical Know ERPs reported in this thesis were less apparent when to-be-memorised stimuli were non-nameable. This set of findings suggests that the role of verbal stimuli and its relation to thought differs in the two groups, where ASD individuals are less likely to verbally mediate their memory compared to TD individuals. It is possible that the addition of verbal labels or the use of nameable stimuli engenders an attenuation of the Old-New effect in ASD. These differences in processing may also be associated with the enhanced Old-New effects for non-nameable and novel kaleidoscope images in the ASD group.

Future research should aim to test these speculations with further systematic investigation. For example, to test the hypothesis that the addition of verbal labels diminishes the Old-New effect in ASD, it would be interesting to investigate what would happen if nonsense words were used as stimuli. If the results revealed preserved Old-New effects for novel and non-

pronounceable nonsense words in ASD, it would suggest that diminished Old-New effects found here are indeed results of a verbally-related processing difficulty in this population. A second possibility for future research would involve training participants to learn a set of verbal labels for images that do not have pre-existing verbal labels attached to them. If Old-New effects were found to be diminished when verbal labels were studied (compared to when verbal labels were not studied), it would provide fairly robust evidence to suggest that verbal stimuli (and the use of inner speech to rehearse the stimuli) during cognitive tasks such as recognition, are associated with the attenuated the Old-New effects found for individuals with ASD. A third possibility would be to include a manipulation of rehearsal suppression during study. If TD individuals do engage a verbal strategy to memorise stimuli, it would be expected that this manipulation would diminish Old-New effects in the TD group, whilst leaving Old-New effects in the ASD group relatively unchanged compared to a non-suppression condition. A study by Smith, Gardiner & Bowler (2007) lends some support to this conjecture. They found that rehearsal training was less effective at promoting memory for semantically and phonologically related word lists in adults with ASD than with matched typical comparison participants. Ultimately, results of studies such as those just proposed would help to further clarify the nature of the diminished Old-New effect in ASD.

8.5 How Do These Findings Impact on Other Theoretical Explanations of ASD?

8.5.1 Relational Processing

As discussed in Chapter 1, episodic Remembering involves the self engaging in mental time travel (Tulving, 2005), and the re-creation of the spatial and temporal context of a previously experienced episode. In this way episodic Remembering requires the binding together of elements of an experienced episode (Chalfonte & Johnson, 1996), for example, the binding of the place and time of an event. Episodic memory shares many common attributes with Relational Processing (see Chapter 1). Therefore the findings from Experiments 1 to 5 can also be applied to the theory of impaired Relational Processing in ASD (Bowler et al., 2008b).

The DRM Remember/Know paradigm used for Experiment 3 confirmed that individuals with ASD were just as susceptible to memory illusions as the TD group. These findings provide evidence to suggest that individuals with ASD were aware of the semantic and associative relations of the word lists at encoding. However the results of Experiment 5 provide evidence to suggest that the Relational Processing deficit may also extend to encoding processes. For that Experiment, participants were asked to study item and colour combinations, and were tested for, (1) single feature recognition (i.e., item recognition) and (2) combined feature recognition (i.e.,

item and colour). The results demonstrated marginally diminished overall recognition during both item alone and, item plus colour combinations. These findings suggest that individuals with ASD find tasks that involve encoding combinations of features more difficult compared to single features. However, as the study was not designed to test whether single versus multiple feature encoding instructions effect overall recognition in ASD, there was no control condition (i.e., a condition with instructions to memorise single features of the items was not included). To test this, the study could be repeated with a manipulation of study phase instructions. In one condition, participants could be asked to memorise both the item and its presentation colour, whilst in the second condition participants could be asked to memorise either the item *or* its colour (Red or Blue). The findings from this study would help to clarify whether instructions to memorise multiple features of a studied stimuli, present a particular difficulty for individuals with ASD.

As we have seen, individuals with ASD also show diminished Old-New effects (for word stimuli; Experiment 1, 3, as well as for nameable picture stimuli; Item recognition and late anterior effects in Experiment 5) when verbal labels are involved and no impairment on tasks where verbal labels are not involved (Experiment 4). It is possible to speculate that this pattern of findings results from more of a general impairment with binding the stimulus (line drawing or word) with its verbal label. The suggestion of a Relational Processing deficit for stimulus - word label pairings is in line with the previous suggestion that individuals with ASD experience difficulties with processing combinations of features (line-drawing plus colour of presentation, observed in Experiment 5), and is in line with the observations reported in Experiments 1 and 3 of this thesis, where TD individuals may have been using a word-labelling strategy to memorise the word lists. Future studies designed to investigate Relational Processing deficits in ASD (particularly at encoding) would help to elucidate these observations (for example, see Gaigg et al., 2008; Gaigg, Bowler, Ecker, Calvo-Merino & Murphy, 2010).

8.5.2 Executive Functioning

Individuals with ASD demonstrate impairments in EF (see Hill 2004b for a review) which may be related to the diminished reports of episodic memory we observe in this population. This is because episodic memory shares some characteristic task requirements with tests of EF. For example, the phenomenological experience of episodic memory (autonoetic conscious awareness) involves shifting attention from the current perspective to a past perspective, in order to recall the spatial and temporal context of the episode. The ability to inhibit a response and to shift attention is also measured by many higher order cognitive functions (EF tasks) such as planning, working memory, mental flexibility (shifting set), inhibition of response, generativity and action monitoring (Rabbitt, 1997). Taken together this literature suggests that impairments in

episodic memory may be linked to the deficits we observe in EF ability in ASD.

It is possible to speculate about the nature of the findings from Experiments 1 to 5, in relation to recent findings in tests of EF in ASD. The research presented in section 8.4 demonstrates that individuals with ASD are less likely to use verbal strategies (or inner speech) to aid recognition. This resonates with studies that have provided evidence to suggest that some aspects of EF depend on verbal thinking in TD individuals (Baldo, Dronkers, Wilking, Ludy, Raskin, et al., 2005). Moreover, in a study by Williams et al., (*in press*), (see p. 161), in which participants with and without a diagnosis of ASD were asked to complete the Tower of London puzzle, just over one third of individuals with ASD but almost 90% of the TD group were negatively affected by an articulatory suppression condition. The authors concluded that unlike the TD group, the ASD group were less likely to verbally mediate their planning on the task (i.e., use inner speech). They made this conclusion on the basis that if planning in the ASD group *was* verbally mediated, the ASD group would have shown a similar degree of performance decline the TD group under articulatory suppression conditions. Furthermore the authors observed that the extent to which articulatory suppression negatively affected the ASD group's performance in the task was correlated with the severity of communication difficulty individuals experienced. This finding provides strong evidence to suggest that verbal mediation and the use of inner speech is significantly less relied upon during planning tasks in ASD compared to TD individuals. Similar findings have been observed in tests of task-switching under articulatory suppression conditions in ASD (see p.172). Furthermore, planning in the Tower of London task is akin to episodic future thinking, which is thought to be mediated by the same neural structures as episodic memory (Suddendorf & Corballis, 1997; Wheeler et al., 1997; Buckner & Carroll, 2007; Lind & Bowler, 2010).

Both episodic memory and EF tasks are likely to be verbally mediated for TD individuals, and there is accumulating evidence to suggest that this is less likely to be the case for individuals with ASD. It is also possible that verbal thinking may atypically mediate recognition memory in ASD.

8.5.3 ToM Deficit

As discussed in Chapter 1, Perner's (2000) account of metarepresentational ability suggests that metarepresentation enables both an understanding of false belief and of episodic Remembering. According to Perner and Ruffman (1995) this ability emerges between the ages of three to six years of age, prior to which children do not understand what experience is, and in turn, cannot reflect upon the perceptual origin of their knowledge. It is only after children are able to encode events as experienced that they can experience episodic Remembering. From this

perspective, it is possible to speculate that poor performance on ToM measures (e.g., false belief tasks, Perner & Wimmer, 1985, see Chapter 1) would suggest impaired episodic Memory. However, this explanation for the diminished Remember judgements observed during behavioural tests of episodic Memory in ASD is not complete. This is because individuals with ASD do not *always* fail ToM tests (see Bowler, 1992; 1997; Dahlgren & Trillingsgaard, 1996).

Higher functioning individuals with ASD are usually only impaired in tests of intuitive mental state understanding (e.g., irony in language, see Happé, 1994a; Bowler, 2007), despite showing diminished episodic memory (Bowler et al., 2000a, b, 2007; Tanweer et al., 2010, replicated in the current thesis Experiments 2 and 4). Moreover, higher functioning individuals who pass higher order ToM tasks have nevertheless been shown to fail non-verbal preferential looking versions of false belief tasks (Senju, Southgate, White & Frith, 2009). Senju et al., (2009) using a task first developed by Onishi and Baillargeon (2005), tested understanding of false belief in adults with ASD using a non-verbal form of the ToM task. The authors demonstrated that individuals with ASD unlike matched individuals with TD, did not look substantially longer when an actor searched in a location for a hidden object that s/he could not know about. That is to say, TD individuals showed preferential looking towards an unexpected outcome (when the actor's behaviour was inconsistent with their belief), whereas ASD individuals did not. The finding that individuals with ASD who pass higher order, verbal ToM tasks, can also fail non-verbal versions of the task suggests that language and thought are not as closely intertwined in ASD, as in TD. Furthermore, these results echo the findings of Williams et al., (*in press*) and are in line with the ERP findings reported in the current thesis.

8.5.4 The Weak Central Coherence Account

The last theoretical account to be discussed is WCC (Happé & Frith, 2006, see Chapter 1). WCC is the notion that individuals with ASD are more likely to process complex stimuli by focusing on the details rather than the overall configuration (highlighting the tendency for a detail-focused cognitive style for people with ASD, see Happé & Frith, 2006). This tendency for local-level processing has been noted in several other theories of ASD, including the theory of Enhanced Perceptual Functioning (Mottron et al., 2006) and Enhanced Discrimination (Plaisted, 2001), (see p. 18). By definition, episodic Remember responses involve combining various pieces of information together, for example, combining the spatial and temporal context of a previously experienced event into a multi-feature representation (Schacter & Tulving, 1994). In this way, episodic memory could be argued to require a global (rather than local) processing style. It is possible to speculate that tests of episodic memory and tasks involving a global processing style, both tap a similar mechanism, however, there is currently no robust evidence that links episodic/semantic memory and WCC. Future research could assess the relationship

between WCC and diminished episodic memory in ASD by testing a large sample of individuals with ASD (and a matched TD group) on a series of tasks aimed at assessing each of these cognitive functions. Episodic memory could be assessed with multiple measures such as the Remember/Know paradigm (Tulving, 1985b), Source monitoring tasks (Wheeler et al., 1997), free recall tasks (Perner & Ruffman, 1995) and tests of 'episodic future thinking' or 'prospection' (see Suddendorf & Corballis, 1997; Wheeler et al., 1997; Buckner & Carroll, 2007; Lind & Bowler, 2010). Multiple measures of WCC would also be gathered, for example, the Block Design test, Embedded Figures Test and tests of homograph reading (see section 1.2.1 of this thesis, also see Happé & Frith, 2006). With these data, it would be possible to run a regression analysis to uncover the extent to which these two phenomena overlap. However, because there is no current evidence to link WCC and episodic memory, the findings presented in this thesis will not be interpreted any further according to this account.

8.6 Future Research

The findings from the present research are generalisable only to higher functioning individuals with ASD. The differences observed and reported here are conservative measures of the behaviourally diminished episodic memory function in LFA individuals. Nevertheless the bias towards higher functioning individuals included in these studies is thought to work against the hypotheses of the studies reported. For a more complete understanding of how individuals with ASD Remember and Know words and picture stimuli it is necessary to investigate younger and lower-functioning groups from the autism spectrum. Although there was access to a limited number of lower functioning individuals with ASD during data collection for the present research, they were not included for two main reasons; (1) the tasks were relatively long and demanding (compared to behavioural tests), which put demands on concentration required from participants, and (2) participants who displayed consistent mannerisms (which tend to be more extreme for lower functioning individuals) could not be included in the experiment due to excessive movement artifact. Nevertheless research would benefit to see if the preserved phenomenological experiences of episodic memory judgements extend to lower functioning individuals, or if they show further qualitative disruption in this sub-population. Such research could utilise the non motion-limiting methodology of Near Infra-red Spectroscopy (NIRS), which measures the hemodynamic signal (oxygenated and deoxygenated blood) in the cortices of the brain and has a similar temporal resolution to EEG methodology.

8.7 Caveats

8.7.1 EEG Noise

A noted caveat in relation to the ERP research presented in Experiments 3, 4 and 5 in

this thesis is that the standard deviations for the ERP amplitudes at each region of interest were large, suggesting that the ERP data were somewhat noisier than the ideal. This is not surprising given that this research has been conducted on individuals with ASD where movement/mannerisms are expected. Nevertheless, these issues should be addressed as a possible shortcoming of the ERP measures taken (see tables 5.5, 6.3 and 7.3) As a consequence, the interpretations of the data made in the preceding sections must be approached with caution.

8.7.2 Counterbalancing

Experiments 1, 2 and 4 counterbalanced the full range of stimuli, to present them as both Targets and Lures across participants. In Experiments 1, 2 and 4, half the conditions presented 50% of the stimuli as Targets and 50% as Lures. For the other half of the conditions, Target and Lure stimuli were flipped. The same counterbalancing version of the experiment was administered to each ASD individual and their matched TD counterpart. Counterbalancing was done in order to reduce the possibility that the results of the study were attributable to differences between study and test stimuli.

It was not possible to fully counterbalance Target, False Target and Lure stimuli for Experiment 3 (without a considerable reduction in the number of stimuli presented at study) as it employed the DRM memory paradigm (Deese, 1959; Roediger & McDermot, 1995). A decision to counterbalance between Target/ False Target/ Lure stimuli across participants would have resulted in a reduction in the number of trials and therefore in the total number of ERPs collected for each participant. For Experiment 3, Lure words were individually matched to False Target stimuli on Imagability (Kucera & Francis, 1967), written frequency, and number of syllables (taken from the Medical Research Council Psycholinguistic database
http://www.psy.uwa.edu.au/mrcdatabase/uwa_mrc.htm).

Experiment 5 employed a complex study design where each study block of 50 images included 32 study images (16 presented in red and 16 in blue) and 18 test images. Of the 32 study images, 12 were assigned to the Item memory study phase and 20 to the Context memory study phase (only 10 of which were presented in the participant's target colour for that block). Of the 18 test images, 12 were assigned to the Item recognition test and 6 to the Context memory test. This resulted in a total of 24 test images being presented in the Item memory phase and 26 test images in the Context memory phase, for each block (see section 7.1.2.2). The purpose of this design was first, to approximately equate the proportions of 'Old' items presented for the Item test (12 out of 24), and 'Target' items presented in the Context memory test phase (10 out of 26). Secondly, ensure adequate numbers of ERP trials in each of the conditions to compare

ERP averages. Similar to Experiment 3, due to the limited number of stimuli (400) matched on name agreement, familiarity, visual complexity and category membership, available in two databases (Snodgrass and Vanderwart, 1980; Cycowicz et al.,1997) the current shortfalls of employing this design are that Study and Test stimuli could not be entirely counterbalanced across participants without a considerable reduction in numbers of stimuli presented to participants. However, within the constraints of the experimental design, the best attempt was made to ensure that as many stimuli as possible were counterbalanced in this way.

Although stimulus matching was rigorous in Experiments 3 and 5, it is nevertheless possible that participants may have recognised different subsets of stimuli and that the differences in stimuli recognised were responsible for group differences observed in the ERPs. Future research should focus on combining the smaller stimuli databases used in this study, into larger stimuli sets, which can be normed and accordingly matched on stimuli categories (such as those listed above). These stimuli sets can then be used in similar studies to those conducted here to ensure the ERP differences between groups observed in this study are not due to differences in the stimuli recognised between groups.

Concluding Remarks

The work carried out in the present thesis aimed to refine models of memory in ASD and elucidate the similarities and differences in performance between these individuals and a group of matched TD individuals. This thesis built upon the existing behavioural research on memory in ASD, by linking established patterns of memory strengths and weaknesses in this population with ERP findings for episodic and semantic memory in TD.

Overall, with minor exceptions, undiminished recognition memory performance was confirmed, together with diminished Remember judgements for individuals with ASD. Recognition memory Old-New effects were diminished for individuals with ASD, but this was not a result of atypical Remember-related ERPs, but unexpectedly, Know-related ERPs. This occurred across a range of test paradigms. The pattern of ERP differences differed between groups according to the type of experimental stimuli that were used.

Verbal labels for studied stimuli appear to be important for individuals with ASD, as atypical Know-related ERPs were less often observed when words or nameable stimuli were not involved. These findings have important implications for our understanding of the relationship between thought and speech in individuals on the autism spectrum.

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Appendices

Appendix 1

TD Group

Remember
I remember that scarf was the 3rd or 4th word in the list.
I remember seeing it flash up on the screen.
I imagined the pen with some ink. These were indelible to me.
I had linked apricot to emerald and imagined an emerald apricot.
I also imagined a musician drinking cider.
I remembered wearing a watch.
I remembered because there is paper on the desk.
I imagined a guard, and I remember watch, hallway, poster and scarf flashing on the screen.
'Yellow' was a colour and the rest were things.

Know
I knew it was there, but I couldn't attach it to the group of words.
They felt familiar.
It seemed likely that it showed up.
I felt sure it had appeared but it hadn't triggered an image

ASD Group

Remember
Crucifix: Not a common word and faith related.
Minister : also faith related
I remembered a yellow scarf
Stapler: I imagined the mouse was a stapler
Bottle: I have a bottle in my bag
Scarf: Imagined my tie was a scarf
Yellow: the table is yellow
I remember seeing a pen on the desk
I associated scarf with cloth
I remembered a massive cranberry I had imagined was hanging down from the ceiling
I remembered someone was sitting on the sofa.
List: the words were in a list

Know
I have no reason to back up why I know it was on the list.
Well I am sure it was on the list, I don't have a reason. It was just on the list I saw.
I probably saw it but I cannot remember where.
I just know that one.
It was a gut feeling.
I know watch was definitely on the list, but I didn't make an association
Scarf: I know that was there but I cannot say why I know.

Appendix 2

Dear participant,

You have just watched a presentation of words appear on a computer screen and were asked to classify those you recognised into either 'Remembered' words or 'Known' words. We would now like you to fill in this short questionnaire before we continue with the task. Afterwards you will have the chance to go through these answers with one of the experimenters.

Please refer back to the 'Remember' and 'Know' answers you gave in the practice trial to answer these questions.

Please read the statements below and place either an 'R' or 'K' inside the box depending on whether you think the statement best reflects a 'Remember' or 'Know' response.

☐   I recall where it appeared in the list of words, (beginning / end / middle) or after another word   that I also recall.

☐   I cannot locate when the word appeared but it definitely appeared in the study phase.

☐   I recall something specific about this word.

☐   I am sure that this word definitely appeared but I cannot tell you why I am so sure.

☐   I imagined something after seeing this word.

☐   I recall something else about the time the word was presented.

☐   This word seemed extremely familiar to me but there is no specific reason for why it is familiar.

☐   I am just sure the word appeared in the study phase.

Are there any other reasons you gave a 'Remember' or 'Know' response that you would like us to know about? Please write them here.

Remember:
Know:

Thank you. Please hand this to the experimenter to continue. After a short talk with the experimenter you will continue onto the task.