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Atypical neurophysiology underlying episodic and semantic memory in adults with Autism Spectrum Disorder

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Running head: Memory in autism spectrum disorder

Caption:
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Abstract

Individuals with Autism Spectrum Disorder (ASD) show atypicalities in episodic memory (Boucher, Mayes & Bigham, 2012). We asked participants to recall the colours of a set of studied line drawings (episodic judgement), or to recognize line drawings alone (semantic judgement). Cycowicz et al., (2001) found early (300 ms onset) posterior old-new event-related potential (ERP) effects for semantic judgements in typically developing (TD) individuals, and occipitally focused negativity (800 ms onset) for episodic judgements. Our results replicated findings in TD individuals and demonstrate attenuated early old-new effects in ASD. Late posterior negativity was present in the ASD group, but was not specific to this time window. This non-specificity may contribute to the atypical episodic memory judgements characteristic of individuals with ASD.

Key words: Memory, Episodic, Semantic, Source Memory, Autism Spectrum Disorder, Event-related Potential

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List of abbreviations:

AQ	Autism Quotient
EEG	Electroencephalography
ERP	Event-related Potential
FIQ	Full Intelligence Quotient
M	Mean
PIQ	Performance Intelligence Quotient
TD	Typically Developing

Atypical neurophysiology underlying episodic and semantic memory in adults with Autism Spectrum Disorder

It is now generally agreed that there are 5 separate, but interacting memory systems (Nadel, 1992; Squire, 2004), 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. Declarative memory allows the cognitive registering of relations between objects and events (Tulving, 1985). 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). The episodic and semantic memory systems are thought to be the most developed of the five human memory systems because they are open to conscious awareness (Schacter & Tulving, 1994). Semantic memory is the memory system responsible for timeless facts, such as the boiling point of water (and is *context-free*), whilst episodic memory is responsible for personally experienced and *Remembered* events that allow an individual to re-experience an event from the past (and is *context-rich*).

Research in recent decades has highlighted a characteristic profile of memory abilities in Autism Spectrum Disorder (ASD), (see Bowler & Gaigg, 2008; Boucher, Mayes & Bigham, 2012, for reviews). In general, high functioning individuals with ASD show preserved semantic memory. Evidence for this is borne out of studies that have investigated immediate memory, cued recall and recognition in ASD (Boucher & Bowler, 2008; Bowler, Matthews & Gardiner, 2007; Boucher and Lewis, 1989). By contrast, they show some impairment on measures of episodic memory, including tests such as free recall (Smith et al., 2007; Boucher & Warrington, 1976), and significantly diminished memory for personally experienced events (Bruck, London, Landa & Goodman, 2007; Crane & Goddard, 2008; Tanweer, Rathbone & Souchay, 2010). They especially fail to use semantic relations amongst studied items to aid free recall (Bowler et al., 1997) and fail to learn as rapidly as comparison participants when the task involves multiple trials

(Bowler, Gaigg & Gardiner, 2008b; Bowler, Mottron & Limoges, 2009). The recall/recognition difference in performance is also evidenced in source memory (Bowler, Gardiner & Berthollier, 2004; Lind & Bowler, 2009b; Russell & Jarrold, 1999) and memory for incidentally-encoded context (Bowler, Gaigg & Gardiner, 2008). All of these observations point towards atypicalities in the episodic memory system in ASD (see Wheeler, Stuss & Tulving, 1997), a conclusion that has been further supported by studies of episodic future thinking in ASD (Lind & Bowler, 2010, but see also Crane, Lind & Bowler, in press). Episodic future thinking has been shown to rely on a set of neural mechanisms that overlaps with that mediating episodic memory (see D'Argembeau, Raffard & Van der Linden, 2008; Spreng, Mar & Kim, 2009),

The Remember/Know paradigm (Tulving, 1985) was developed to measure the contribution of the episodic and semantic memory systems to overall recognition memory. The paradigm involves presenting participants with a list of stimuli which they are asked to memorise, after which they are given a recognition memory test. At 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. Participants are instructed to make a Remember response if they are able to recollect something specific about the time the stimulus was presented such as what they thought about or where precisely in a list a certain stimulus occurred. Thus, Remembering involves the conscious recollection of the Self in subjective time. By contrast, Knowing that a stimulus appeared implies an absence of such autonoetic recollection, and a more 'selfless' knowledge that the stimulus has been previously encountered. Individuals with ASD have been shown to have a diminished episodic memory as measured using Remember/ Know paradigms (Bowler, Gardiner & Grice, 2000a; Bowler, Gardiner, Grice & Saavalainen, 2000b; Bowler et al., 2007; Boucher & Bowler, 2008; Boucher, Mayes & Bigham, 2012). However, although episodic Remember judgements are diminished in quantity in ASD, the phenomenology of the experience, and quality of these judgements seems to be comparable to typically developing individuals. For example, Bowler et al. (2007) drew upon a series of manipulations known to differentially effect Remember and Know responses in TD individuals, and demonstrated similar behavioural observations for ASD individuals. When attention was divided at study, both ASD and TD individuals exhibited a greater reduction in Remember than Know judgements relative to a ‘full’ attention condition. When different modalities were used at test and study, (e.g., visual versus auditory presentation) Know judgements are modulated, but Remember judgements were not. And false identification was found to be more likely for a late phoneme change (‘paradife’) than early phoneme change (‘faradise’, for the word ‘paradise’). This manipulation also selectively increased Know judgements in both TD and ASD individuals. Finally, Bowler et al (2007) confirmed that when items were presented three times at study, Remember responses selectively increased relative to a single presentation. These results provide additional support for the argument that experiences of Remember and Know are qualitatively similar between groups. Thus, according to these studies, it seems that individuals with ASD can have similar experiences to TD individuals when making episodic Remember responses, which leads us to the question of *why* the baseline differences in episodic remembering may exist between groups, Several factors have been implicated in ASD, including difficulties with sense of self, emotion processing, mental time travel, language and learning (for a full discussion, see Lind and Bowler, 2008).

To reinforce the validity of the observations above, it is important to extend these findings using methods other than the Remember/ Know procedure that also measure episodic and semantic memory judgements. For example, in one test procedure with TD individuals, Wilding and Rugg (1996) asked participants to memorise a list of words that were presented in two different voices (a male or female voice), thus assigning an ‘experimental context’ to the studied words. During the test phase, participants were presented with a series of words and asked to judge whether they had heard the words before (old) or whether they were hearing the words for the first time (new). For those that were judged as old, participants were asked to provide the context in which it was studied (remember whether it was spoken by a male or female voice). The sequential response method described above (item memory, i.e., old/new judgement, followed by a context memory, i.e., source 1/ source 2) 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. Studies using these paradigms have had converging findings as those from studies using the Remember/ Know procedure in TD individuals.

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 that subserves 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). To understand how much of a contribution the medial temporal lobe makes to memory performance, several researchers have examined memory performance after extensive medial temporal lobe damage, in particular, localized 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-hadem, 2000) and individuals who undergo damage to this area have been shown to exhibit disproportional deficits in episodic recollection (e.g., Yonelinas, Otten, Shaw and Rugg, 2005 or see Aggleton, Vann, Denby, Dix, Mayes, 2005 for similar results in patients with meningoencephalitic hippocampal atrophy).

The lateral parietal and posterior cingulate cortices also have connections with the medial temporal lobe 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 (episodic) 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 and the inferior parietal lobule. Several studies have also consistently revealed activation in the posterior parietal cortex (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 posterior parietal cortex 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 posterior parietal cortex 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 intra-parietal sulcus 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 posterior parietal cortex regions, lateral and posterior to the intra-parietal sulcus 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 posterior parietal cortex 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 intra-parietal sulcus (Wagner, et al., 2005).

Alternatively, neurophysiological electrical brain activity can be investigated using electroencephalography (EEG) and event-related potentials (ERPs) can be used to investigate neurophysiological activity. The strengths of these methods are that they offer temporal resolution in the order of milliseconds, and (by comparison) are less intrusive compared to other measures of brain activity. This has resulted in EEG and ERPs being used to investigate the neurophysiology of individuals from special populations, including persons with ASD. For example, ERPs have been used to investigate basic auditory and visual processing in ASD (see Ouimet, Foster, Tryfon & Hyde, 2012 for a recent review). ERPs have revealed patterns of enhanced and diminished neural processing in both vision (the Enhanced Perceptual Functioning model of ASD, Mottron, Dawson, Soulieres, Hubert, & Burack, 2006), and audition in ASD and is often linked to the neural complexity required to process the stimuli. For example, Bonnel, McAdams, Smith, Berthiaume, Bertone, Ciocca, Burack & Mottron, (2010; also see Samson, Mottron, Jemel, Belin & Ciocca, 2006), found that individuals with ASD compared to TD individuals demonstrated enhanced performance for the processing of simple tones in primary auditory cortical regions, but diminished performance for complex tones, which in addition, require processing in associative regions. ERPs have elucidated our understanding of vision and auditory processing in ASD, and are of significant value to our understanding of other, more complex processing in ASD, for example language development.

The brain bases of language abnormalities in individuals with ASD have been extensively studied using auditory ERPs (see Bomba & Pang, 2004 for a review). The P300 or P3 ERP, including both P3a (recorded when participants are actively attending and P3b (recorded during passive attention) have been used to investigate language, and auditory processing in children with Asperger's Disorder (Lepisto, Silokallio, Nieminen-von Wendt, Alku Naatanen & Kujala, 2006), and to investigate how children with ASD orient to unattended changes in their environment (Escera, Alho, Schroger & Winkler, 2000).. The P3a has been found to be diminished in amplitude for adolescents with ASD when elicited by highly attention-catching novel sounds (Courchesne, Kilman, Galambos & Lincoln, 1984), as well as by subtle changes in speech, as opposed to non-speech changes in children with ASD (Lespito, Kujala, Vanhala, Alku, Huotilainen & Naatanen, 2005). Furthermore, the mismatch negativity (an ERP that indexes sound discrimination accuracy), is elicited by a perceptible change in a sequence of repeated sounds (Naatanen, 1992), and studies have shown that in children with ASD, pitch-mismatch negativity is diminished (Seri, Cerquiglini, Pisani & Curatolo, 1999), along with diminished mismatch negativity amplitudes for duration (Lepisto et al., 2005) and consonant changes (Kuhl, Coffey-Corina, Padden & Dawson, 2005). Taken together these results suggest that individuals with ASD have difficulties with sound discrimination..

ERPs may also elucidate questions concerning whether Remember responses for individuals with ASD are qualitatively different or quantitatively different from those of TD individuals (see Curran, 2000; Rugg and Curran, 2007 for a review of findings in TD individuals). ERP old-new effects are amplitude deflections for studied old stimuli relative to new stimuli at retrieval occurring at approximately 300 ms post stimulus lasting several hundred milliseconds (for reviews see Rugg & Curran, 2007; Johnson, 1995). These downward (positive) deflections in the ERP are more often positive for old than for new stimuli in TD individuals, and ERP old-new effects are attenuated post 800 ms in individuals with ASD (Massand, Bowler, Mottron, Hosein & Jemel, 2013).

In TD individuals ERP old-new effects for Remember and Know judgements 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 (i.e., of greater magnitude for successful source judgements compared to unsuccessful ones, Wilding & Rugg, 1996; Senkfor & Van Petten, 1998), which is considered to tap episodic memory.

Old-new effects for items rated as ‘know’ have been temporally and topographically dissociated from those associated with Remember judgements. The first account of this was by Düzel et al. (1997) using the Remember/ Know paradigm. 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 Know judgements would be driving this type of response 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 Remember judgements is reduced during false recognition compared to true recognition whereas the activity associated with Know judgements is equivalent. Taken as a whole, this body of evidence indicates that Know ERPs can be topographically and temporally dissociated from those associated with Remember responses, and suggests that these judgements 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 old/new effects for these judgements. 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 (K judgements), but not when recognition was associated with a Remember response (a correctly identified studied picture relative to correctly rejected lure picture). These findings converge with previous studies using word stimuli and also 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).

Old stimuli that are recognised along with the retrieval of contextual information reflect contributions of episodic memory. In contrast, old stimuli that are recognised without the retrieval of contextual information reflect contributions of semantic memory. Unlike the Remember/ Know paradigm, these tasks define specific attributes of the stimuli that 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, do not count towards episodic memory. Experimentally defined context therefore results in a stringent measure of episodic recollections, and it is these ERP old-new effects that are the focus of the present study. Two ERP old-new effects have been consistently observed for item and context memory. 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 may or may not be accompanied by contextual information, (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) suggest that this late prefrontal old-new effect reflects the search and retrieval of contextual information relating to the studied stimuli, and that this ERP may be associated with the retrieval of episodic memory. This interpretation is consistent with data from studies using functional magnetic resonance imaging (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. In their task, recognition could be (1) void of contextual information from the study phase (item memory task) or, (2) accompanied by the retrieval of contextual information (context memory task). 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), with all test images being 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 the 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. This task required the grouping of images studied in the non-target colour, and new images into the ‘Other’ category (hereafter the context memory test). Only those images that were studied in the participant’s study colour were targets. 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 during the exclusion task. Target ERP old-new effects (judgements that were associated with the successful recollection of study context) demonstrated later, long duration, occipitally focused negativity beginning at 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 identified 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 in Cycowicz et al.,’s study were 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. These findings suggest that the posterior activity reflects a material specific search for contextual information (Cycowicz et al., 2001).

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, then 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) but instead analysed them separately.

Given that in behavioural tasks, individuals with ASD show atypicalities in episodic memory, including diminished free recall, diminished recall of context and diminished recall of source information, we asked participants to recall the colours of a set of previously presented line drawings (episodic judgement) or to recognise the drawings alone (semantic judgement; the Inclusion/Exclusion paradigm). We predicted poorer recall of colour information for individuals with ASD compared to the TD group. We explored three bilateral ERP old-new effects: (1) the early positive old-new effect for item recognition (semantic judgment, onset ~300 ms), (2) the late posterior negative old-new effect for context memory (onset ~800 ms), and (3) the late anterior positive old-new effect for context memory (onset ~800 ms), in ASD. We expected to observe differences in the late posterior negative, and late anterior positive old-new effects in ASD individuals compared to the TD group. It was expected that the variability in the EEG data collected from the ASD group would be greater than for the TD group. This issue has been addressed in the EEG data analysis section.

Method

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. Exclusionary criteria in both groups included mental illness, head trauma or neurological disease, seizures, known brain malformations and current use of psychoactive medicines. The ASD group all had clinical diagnoses, which were made by professionals experienced in the field of Autism. The ASD group all met the Diagnostic and Statistical Manual – IV (DSM-IV- TR, 2000) criteria for Autism or Asperger's Disorder. The group also met Autism Spectrum cut off on the Autism Diagnostic Observation Schedule (ADOS, Lord, Risi, Lambrecht, Cook, Leventhal, DiLavore et al., 2000). All participants were right handed and reported normal or corrected to normal vision. Participants were individually matched to within 7 points of Verbal and Full-scale

IQ using the WAIS-III-R (Wechsler Adult Intelligence Scale-III- Revised) scales of intelligence, and group matched for Performance IQ. This was done to control for the variability in education levels between groups. Groups were matched for Age and Gender. The Autism Spectrum Quotient (or AQ, Baron-Cohen, Wheelwright, Skinner, Martin & Clubley, 2001) was available for a subset of the study sample (11 TD individuals and 13 ASD individuals), and was used to screen the TD group for possible ASD symptoms. All TD participants where data was available on this measure scored within the typical range. Averages and group differences for AQ, Age, Verbal IQ, Performance IQ and Full-scale IQ are presented in Table 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. All participants gave their informed consent prior to their inclusion in the study.

INSERT TABLE 1 HERE

Stimuli

The 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 1. The 300 images were divided into 6 blocks of 50 that were matched on name agreement (F (5, 294) = 1.42, p > .05), familiarity (F (5, 294) = 0.11, p > .05), visual complexity (F (5, 294) = 2.13, p > .05) and category membership (F (5, 294) = 1.48, p > .05). 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. Each participant viewed 6 blocks, which were interspersed with short breaks (hereafter referred to as a block-design experiment). Each 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.

INSERT FIGURE 1 HERE

Participants were asked to study a list of images presented one at a time, and given instructions to memorise the image and its colour (either red or blue) for a later memory test. Special emphasis was placed on remembering both components of the stimuli (accuracy of response was emphasised over speed). During the item memory test, images were presented in black and participants were asked to make an old-new discrimination when a prompt appeared. They were asked to press ‘old’ if they thought the image had been seen during the study phase and ‘new’ if they thought the image had not appeared during study. During the context memory test, images were also presented in black. 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) when the prompt appeared. 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 that presented all stimuli at a viewing distance of 70 cm. Images were presented as large as possible inside a frame that measured 6.5 x 6.5 cm. This resulted in a visual angle of 5.32º.

Pilot testing with an additional 4 participants with a similar IQ as those enrolled in the current study, revealed that in order to achieve a corrected recognition proportion above 0.6 (hits – false alarms) but below ceiling, a study presentation duration of 3 s was required. Importantly, this presentation duration allowed participants sufficient time to successfully memorise the stimuli. Therefore during study, images were presented at a rate of one every 3 s (500 ms central fixation cross and 2500 ms study image presentation). During the item and context memory test, images were presented for a shorter duration of one every 2.5 s (500 ms central fixation cross and 2000 ms image presentation).

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 20 kΩ (Kappenman & Luck, 2010). The EEG signal was recorded with a bandpass of 0.1 - 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 with a bandpass of 0.05-20Hz. The data were then segmented into epochs lasting 1500 ms (including a 200 ms baseline correction pre stimulus and 1300 ms post stimulus). Epochs were 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.

Data Analysis

A 'hit' was defined as a correctly identified old or new image, indicated by a successful 'old' or 'new' button press respectively. 'False alarms' were defined as incorrectly endorsed new images. 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 data, 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, the data gathered from 32 scalp electrodes were clustered into regions of interest, 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 (P8/P4/PO10/O2). In this paper we use the term ‘old-new ERP effect’ to refer to the subtraction of old minus new ERP amplitude waveforms, target minus new ERP amplitude waveforms, and the non-target minus new ERP amplitude waveforms. The magnitude and scalp distribution of old-new ERP effects between groups were assessed on the ERP amplitude differences.

EEG Noise

Differences in noise level can present a problem depending on the measure (i.e., peak amplitude or mean voltage amplitude). Peak amplitude measures can present bias 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. According to Luck (2010) mean voltage amplitude, is a more unbiased measure that can be used when noise levels differ across conditions. 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 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 (Cycowicz et al., 2001; 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.

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. To ensure that topographic comparisons of the ERP data were not confounded by differences in the magnitude of the Old-New effects, significant interactions involving Region by Latency, Task, Sagittal plane and/or by Group were further investigated after normalisation of the EEG amplitudes, using a root mean square z-transformation (RMS-z) of the ERP amplitude measurements (McCarthy & Wood, 1985).

Results

Behavioural Results

The corrected data (hits-false alarms) 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 may have been more difficult for individuals with ASD. The data are presented in Table 2.

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).

INSERT TABLE 2 HERE

ERP Results

The analysis 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. To compare categories of stimuli in the item memory task, ERP amplitudes for correctly rejected new items were subtracted from correctly identified items. Similarly, for the context memory test, correctly rejected target and non-target item ERP amplitudes were subtracted from ERP amplitudes for correctly identified items. Voltage difference amplitudes were calculated for each individual, and at each electrode (old minus new amplitudes). Mean voltage amplitude differences were calculated for the time windows of interest (following Cycowicz et al., 2001). 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.*).

Description of ERP old-new effects

For TD individuals, observable amplitude differences were present for item, target and non-target early old-new effects (300-650 ms), where previously studied stimuli had more positive amplitudes compared to new stimuli. The effect was observed at right anterior and central regions. For ASD individuals, early old-new effects appeared diminished for all three classes of stimuli at these locations (see Fig. 2 for ERP data). From 950-1200 ms, old-new effects were observed for target and non-target stimuli were present in both groups, where previously studied stimuli demonstrated negative amplitudes compared to new stimuli at posterior locations, and positive amplitudes compared to new stimuli at anterior locations from (see Fig. 3 for ERP data; also see Figs. 4 & 5 for scalp plots).

INSERT FIGURE 2; 3; 4; 5; 6 HERE

A 3 (Task) x 3 (Region) x 3 (Sagittal Plane) x 2 (Latency) x 2 (Group) Repeated Measures ANOVA was run using old minus new difference values, and is presented in Table 3. ANOVA revealed a main effect of Latency (F (1, 31) = 104.72, p<.01, *partial* η^2 = .77, power = 1), which was qualified by a significant Latency x Sagittal Plane interaction (F (2, 62) = 33.85, p<.01, *partial* η^2 = .52, power = 1) and Latency x Region x Sagittal Plane interaction (F (3.27, 101.44) = 4.30, p<.01, *partial* η^2 = .12, power = .92). 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, *partial* η^2 = .35, power = .99) and differed between groups (Latency x Region x Group interaction F (1.40, 43.25) = 4.69, p<.05, *partial* η^2 = .13, power = .65). The Task x Latency x Region x Group interaction was significant (F (1.69, 52.46) = 3.18, p<.05, *partial* η^2 = .09, power = .54). 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.

INSERT TABLE 3 HERE

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, *partial* η^2 = .16, power = .65) where the old-new difference was larger for the TD group than ASD group. Separate analyses for each group revealed significant positive old-new effects for the TD group (main effect of old-new was significant F (1, 17) = 24.76, p<.01, *partial* η^2 = .59, power = .99) that did not differ across tasks (main effect of Task F (2, 34) = 0.09, p = *n.s.*). For the ASD group the old-new effect did not reach significance, see Figure 6 (F (1, 14) = 2.13, p = *n.s.*), and was significantly attenuated overall.

Late old-new effect (950-1200 ms)

The amplitude and topography of the late old-new effect was investigated in both groups using 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, *partial* η^2 = .13 power = .69). Separate ANOVAs for each region showed that the TD group demonstrated significantly more positive anterior old-new effects (F (1, 31) = 4.14, p = .05, *partial* η^2 = .12, power = .50) and significantly more negative posterior old-new effects (F (1, 31) = 6.77, p<.05, *partial* η^2 = .18, power = .71) compared to the ASD group. 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, *partial* η^2 = .56, power = 1) 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, *partial* η^2 = .28, power = .91) and Latency x Task x Group interaction (F (1.31, 40.57) = 3.72, p = 0.05, *partial* η^2 =

.11, power = .53). Furthermore when the analysis was repeated for each task separately, significant Latency x Group interactions, for non-targets (F (1, 31) = 10.50, $p<.01$, *partial* η^2 = .25, power = .88) and targets (F (1, 31) = 8.60, $p<.01$, *partial* η^2 = .22, power = .81) 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 for each latency interval. 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

To investigate the amplitude and topography of the old-new effect at the anterior electrode cluster, 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, $p<.01$, *partial* η^2 = .32, power = .96) which was qualified by a significant Latency x Group interaction (F (1, 31) = 4.00, p = .05, *partial* η^2 = .11, power = .49). 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, $p<.01$, *partial* η^2 = .38, power = .87), 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 4.

INSERT TABLE 4 HERE

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 target recognition would be diminished in ASD compared to TD individuals (Bowler et al., 2000a, b, 2007; Tanweer et al., 2010), with preserved item recognition, however marginally diminished item, target and non-target recognition scores were also observed in the ASD group. This finding suggests that ASD individuals found all three tasks more difficult compared to matched controls. 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 suggest that recognition memory judgements are accompanied by 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, anterior positivity was observed in the TD group and was enhanced from 950-1200 ms compared to 300-650 ms. The amplitude of this 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 memory in this population. Furthermore, this difference may be associated with fewer 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 old-new 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. 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.

Weaknesses and future directions

The task demands in the present study were for participants to memorise the picture along with its presentation colour (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 test 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 of 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), suggesting that this ERP effect may have included a contribution from Remember responses (at least on some trials). This early old-new effect was diminished in the ASD group, and this observation 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 study.

Lastly, noteworthy caveats of the current study are that standard deviations for the ERP amplitudes at each region of interest were large, suggesting that the ERP data were somewhat noisier than the ideal. However, this was expected given that this research has been conducted on individuals with ASD, where movement/mannerisms are common. In addition for some analyses the observed power was below the ideal. One direction in which future research could improve upon the existing study and reduce this variability, and increase power would be to include a larger sample size. These issues should be addressed as possible shortcomings of the measures taken.

Summary and conclusion

In summary, the findings from this study demonstrated marginally diminished behavioural recognition memory performance in ASD, which was accompanied by an atypical patterning of 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 (950-1200 ms) was observed in both groups. 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 suggest that whilst in TD, two memory systems have emerged, a single non-differentiated system may underlie memory in ASD, and it is likely that the neural correlates of both episodic and semantic memory are compromised in ASD. Therefore, it is important that educators and clinicians are aware that although behavioural performance of individuals with ASD may appear normal, the neural mechanisms are likely compromised.

The authors declare that they have no conflict of interest.

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	ASD (N=15)		TD (N=18)		Group differences
	M (range)	SD	M (range)	SD	
Age (years)	38.89 (20.10 – 55.92)	14.77	37.17 (20.98 – 59.93)	11.84	t = -0.55, d.f. = 31, p = *n.s.*
VIQ	114	11	111	17	t = -0.74, d.f. = 31, p = *n.s.*
PIQ	111	14	109	16	t = -0.09, d.f. = 31, p = *n.s.*
FIQ	114	13	111	18	t = -0.54, d.f. = 31, p = *n.s.*
AQ	35	7.08	16	6.05	t = -7.16, d.f. = 22, p <.001

Table 1: Mean (M), standard deviations (SD) and analyses for group differences (independent samples *t*-tests) for Age, AQ and IQ measures (WAIS-III-R). VIQ = Verbal IQ, PIQ = Performance IQ, FIQ = Full-scale IQ.

	TD (N=18)		ASD (N=15)		Both Groups (N=33)	
	M	SD	M	SD	M	SD
Items						
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
Targets						
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-targets						
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 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 individuals.

Effect:	d. f.	F	p
Latency (L)	1, 31	**104.72**	<.01
Task (T)	2, 30	0.64	*n.s.*
Region (R)	1.24, 38.24	**3.76**	<.05
Sagittal (S)	2, 30	14.49	*n.s.*
Group (G)	1, 31	2.86	*n.s.*
L x G	1, 31	2.73	*n.s.*
L x R	1.4, 43.25	**16.59**	<.01
L x T	1.42, 43.85	1.06	*n.s.*
L x S	2, 62	**33.85**	<.01
R x G	1.43, 44.34	0.95	*n.s.*
R x T	2.28, 70.55	1.86	*n.s.*
R x S	3.41, 105.79	1.57	*n.s.*
T x S	4, 28	2.09	*n.s.*
T x G	1.85, 57.47	1.38	*n.s.*
S x G	2, 61.98	**3.67**	*<.05*
L x R x S	3.27, 101.44	**4.30**	<.01
L x R x G	1.4, 43.25	**4.69**	<.05
L x R x T	1.77, 54.87	1.01	*n.s.*
L x T x G	1.42, 43.85	1.20	*n.s.*
L x S x G	1.73, 53.46	0.71	*n.s.*
L x T x S	2.95, 91.33	0.49	*n.s.*
R x S x G	3.41, 105.79	0.21	*n.s.*
T x L x R	1.69, 52.46	1.46	*n.s.*
R x T x S	5.31, 164.49	1.09	*n.s.*
T x R x G	2.28, 70.54	0.35	*n.s.*
T x S x G	3.72, 115.37	**3.15**	*<.05*
T x L x R x G	1.69, 52.46	**3.18**	<.05
L x R x S x G	3.27, 101.44	0.48	*n.s.*
L x T x S x G	2.95, 91.33	1.80	*n.s.*
L x R x T x S	4.20, 130.32	1.71	*n.s.*
R x T x S x G	5.31, 164.49	0.92	*n.s.*
L x R x T x S x G	4.20, 130.32	1.39	*n.s.*

Table 3: ANOVA results from the voltage analysis. Greenhouse-Geisser corrections are reported where sphericity is violated. Bold values are significant at p<.05, or lower.

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 4 (A) Summary of findings for semantic memory old-new effects. (B) Summary of findings for episodic memory old-new effects. TD individuals showed old-new effects specific to the late time window. ASD individuals' old-new effects were present during both time windows.

X = old-new effect not present, □ = old-new effect present.

Figure 1 top

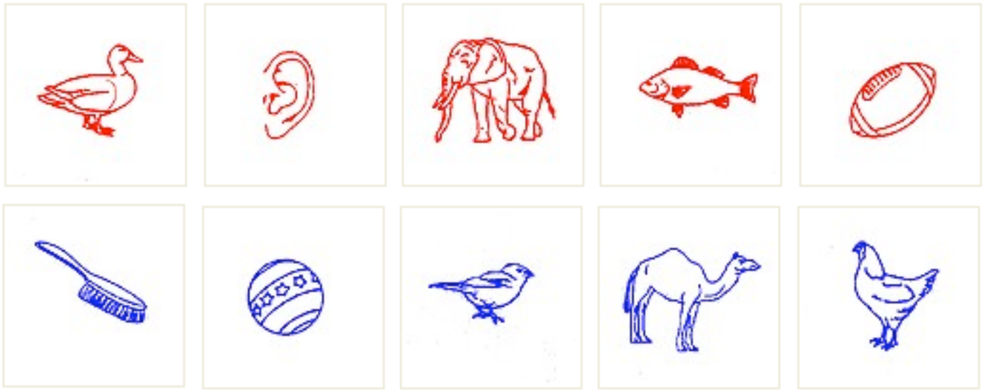
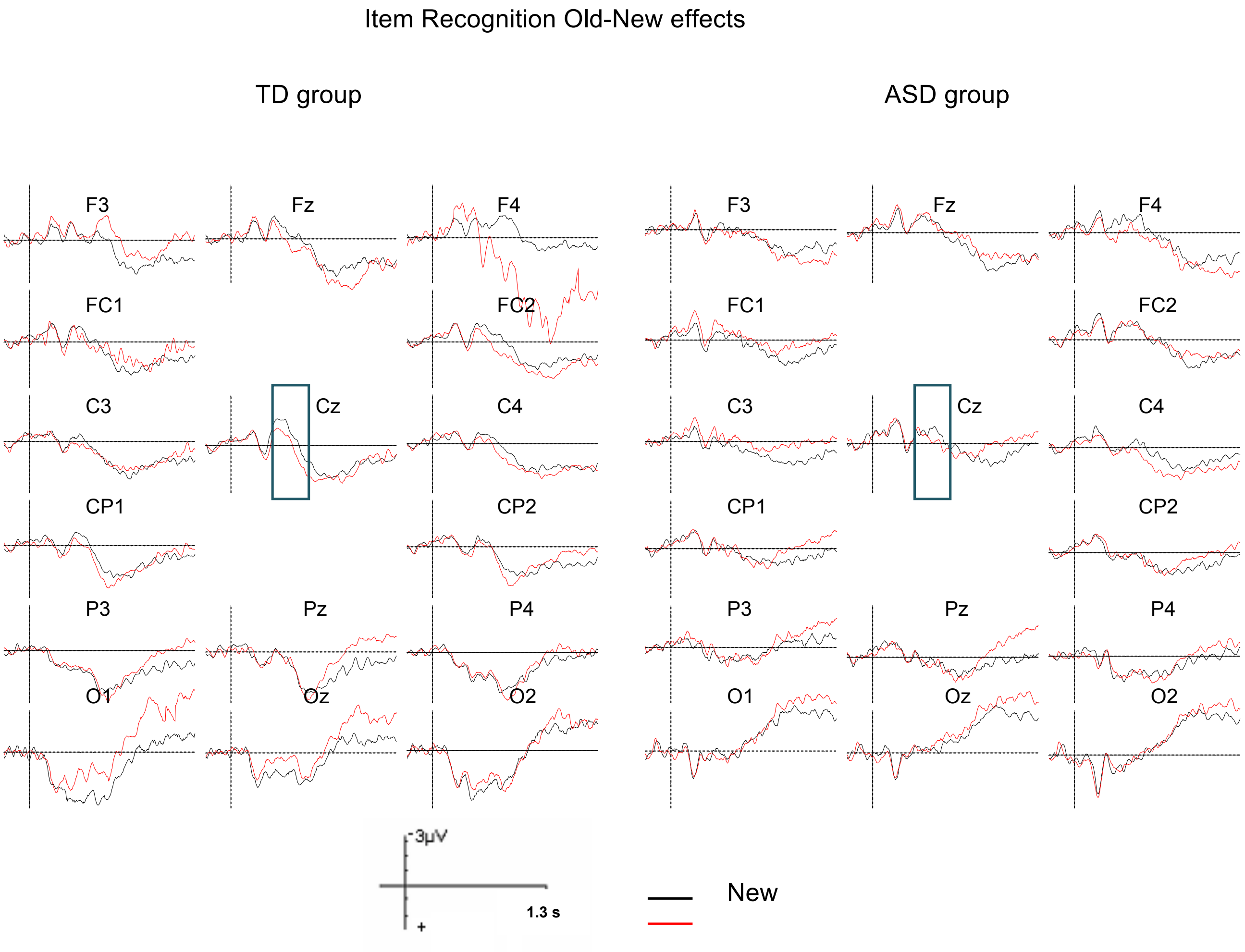


Figure1: Examples of studied stimuli.

Figure 2 top


Item Recognition Old-New effects

TD group

ASD group

Figure 2: Item Old-New effects for TD (N=18) and ASD (N=15) groups shown at sixteen selected electrodes.

Figure 3 top

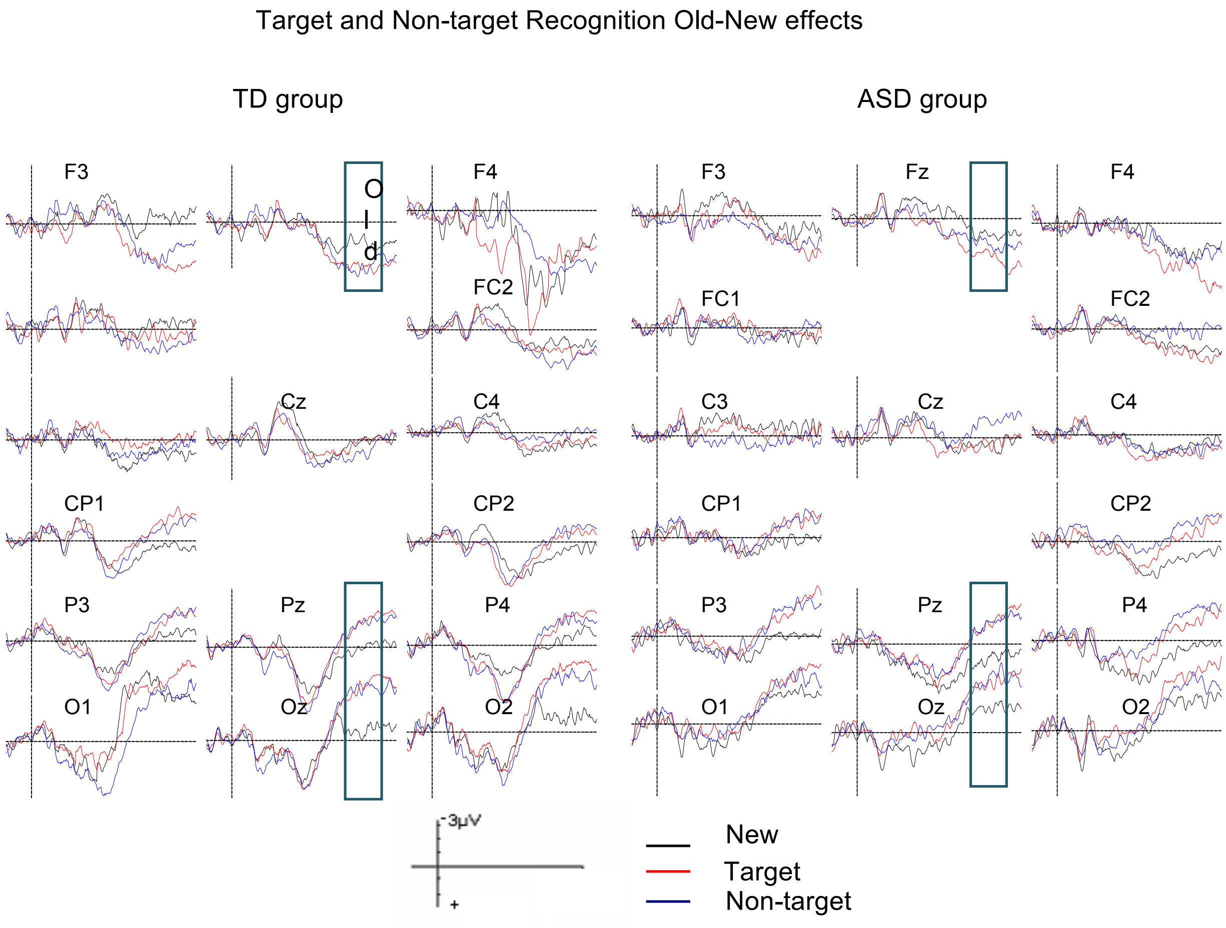


Figure 3: Target and Non-target ERP Old-New effects for TD (N=18) and ASD (N=15) groups, shown sixteen selected electrodes.

Figure 4 top

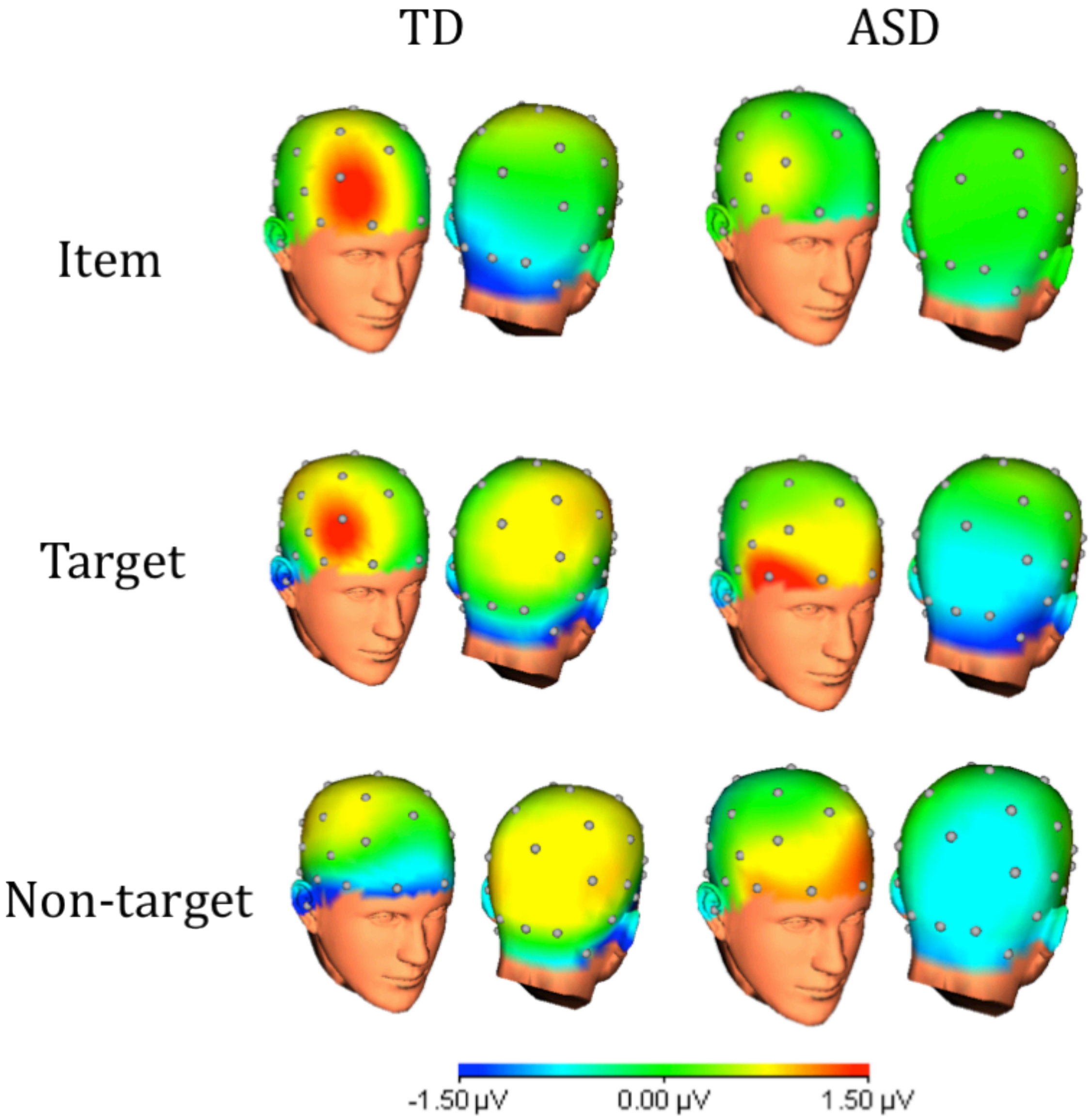


Figure 4: Scalp distributions of item, target and non-target old-new ERP amplitude differences (old minus new words) from 300-650 ms for TD (N = 18) and ASD (N = 15) groups.

Figure 5 top

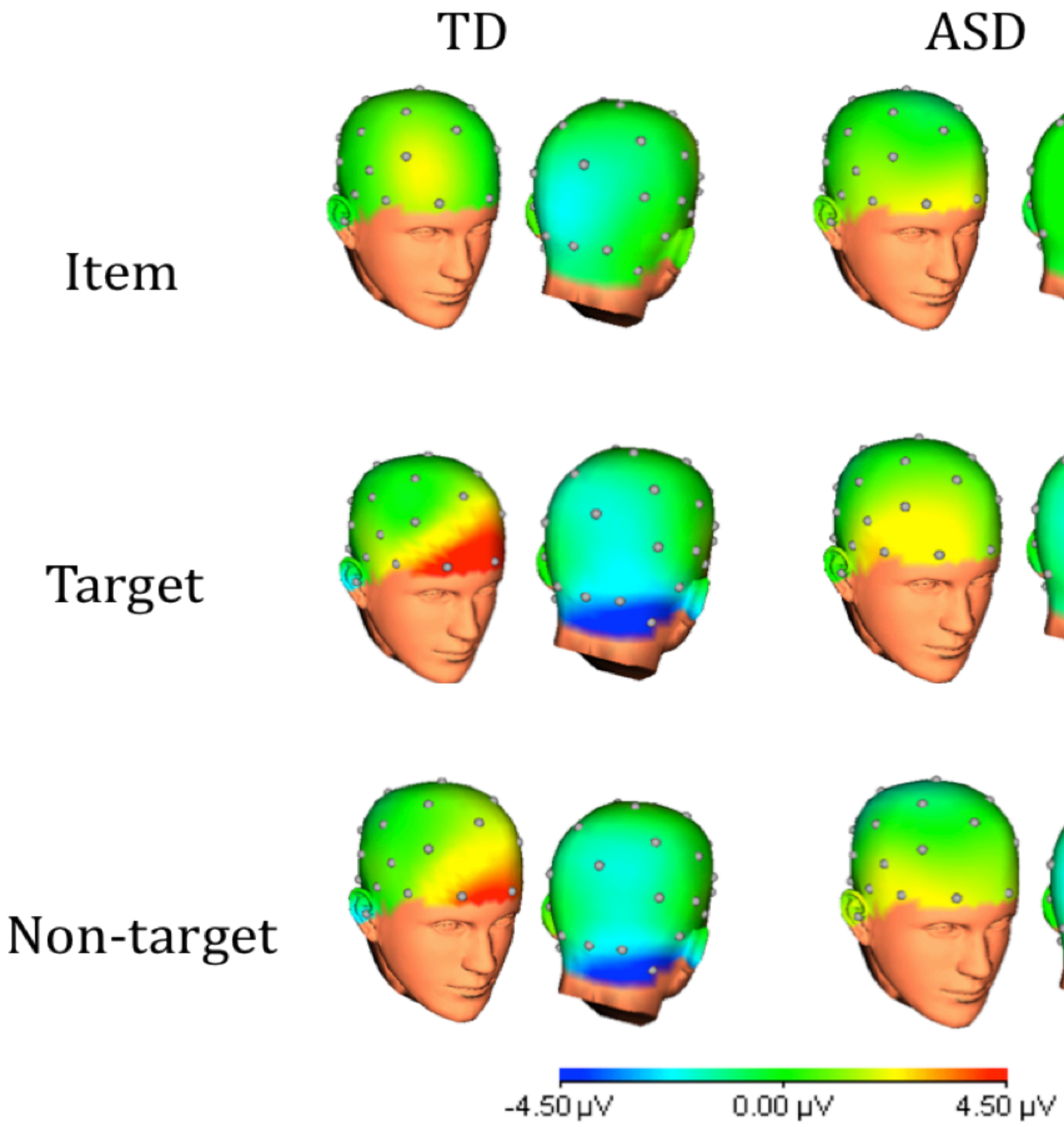


Figure 5: Scalp distributions of item, target and non-target old-new ERP amplitude differences (old minus new words) from 950-1200 ms for TD (N = 18) and ASD (N = 15) groups.

Figure 6 top

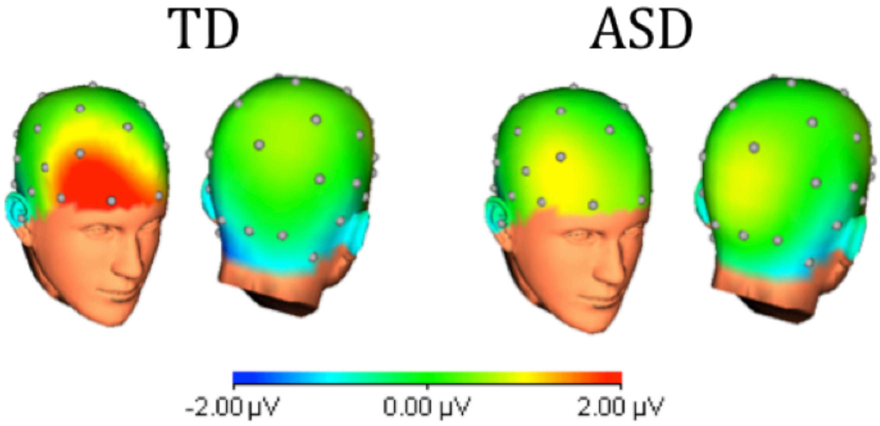


Figure 6: Early old-new effect (300-650 ms) for item, target and non-target trials (combined) in the TD and ASD groups.