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Eye movements reveal a dissociation between memory encoding and retrieval in adults with autism

Rose A. Cooper [a], Kate C. Plaisted-Grant [a], Simon Baron-Cohen [b], Jon S. Simons [a,*]

[a] *Department of Psychology, University of Cambridge, Cambridge CB2 3EB, UK*
[b] *Autism Research Centre, Department of Psychiatry, University of Cambridge, Cambridge CB2 8AH, UK*

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ABSTRACT

People with Autism Spectrum Disorder (ASD) exhibit subtle deficits in recollection, which have been proposed to arise from encoding impairments, though a direct link has yet to be demonstrated. In the current study, we used eye-tracking to obtain trial-specific measures of encoding (eye movement patterns) during incidental (natural viewing) and intentional (strategic) encoding conditions in adults with ASD and typical controls. Using this approach, we tested the degree to which differences in encoding might contribute to recollection impairments, or whether group differences in memory primarily emerge at retrieval. Following encoding of scenes, participants were asked to distinguish between old and similar lure scenes and provide 'remember'/'familiar' responses. Intentional encoding increased eye movements and subsequent recollection in both groups to a similar degree, but the ASD group were impaired overall at the memory task and used recollection less frequently. In controls, eye movements at encoding predicted subsequent correct responses and subsequent recollection on a trial-by-trial basis, as expected. In contrast, despite a similar pattern of eye movements during encoding in the two groups, eye movements did not predict trial-by-trial subsequent memory in ASD. Furthermore, recollection was associated with lower similarity between encoding- and retrieval-related eye movements in the ASD group compared to the control group. The eye-tracking results therefore provide novel evidence for a dissociation between encoding and recollection-based retrieval in ASD.

1. Introduction

Autism Spectrum Disorder (ASD) is primarily associated with social interaction and communication difficulties as well as restrictive and repetitive behaviours, although the presence of memory deficits in people with ASD has also been widely observed in recent years, particularly affecting the recollection of previous experiences (see Boucher, Mayes, & Bigham, 2012 for a review). Recollection is defined by a threshold process of recalling the specific details and spatial-temporal context of a particular stimulus whereas familiarity is defined by a feeling of knowing a stimulus has been encountered before without accompanying recollection of the event details (Yonelinas, 2002). Deficits in recollection have been observed across a range of tasks in ASD, including reduced memory for an item's original context (e.g. Bowler, Gaigg, & Gardiner, 2014; Bowler, Gardiner, & Berthollier, 2004; Cooper, Plaisted-Grant, Baron-Cohen, & Simons, 2016; Lind & Bowler, 2009; Ring, Gaigg, & Bowler, 2015) and a reduction in subjective reports of recollection during recognition memory (Bowler, Gardiner, & Gaigg, 2007; Cooper et al., 2015; Gaigg, Bowler, Ecker, Calvo-Merino, & Murphy, 2015; Meyer, Gardiner, & Bowler, 2014), despite typical familiarity-based recognition memory.

Most theories aiming to account for the pattern of memory performance in ASD focus on encoding as the potential basis of recollection deficits (cf. Boucher et al., 2012), but the relative contributions of encoding and retrieval dysfunction remain underspecified. This is because determining whether an item has been encoded can often only be achieved by testing memory for that item later on, meaning that encoding and retrieval processes are difficult to tease apart. For instance, impairments characterised by theories focused on encoding, such as deficits in complex information processing (Minshew & Goldstein, 2001) and relational binding (Bowler, Gaigg, & Gardiner, 2008; Bowler et al., 2014), could easily arise due to deficits in strategic retrieval (cf. Cooper et al., 2015; Solomon, McCauley, Iosif, Carter, & Ragland, 2016). Similarly, the task support effect (Bowler et al., 2004), highlighting that retrieval cues (reducing strategic retrieval demands) ameliorate

* Corresponding author at: Department of Psychology, University of Cambridge, Downing Street, Cambridge CB2 3EB, UK.
E-mail address: jss30@cam.ac.uk (J.S. Simons).

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recollection deficits in ASD, could arise due to deficient encoding (cf. Meyer et al., 2014). Hence, encoding and retrieval explanations of recollection deficits in ASD that have been proposed to date have not been sufficiently distinguished from one another.

In order to dissociate these two stages of memory, it is important to manipulate and measure aspects of encoding independently of retrieval. One recent suggestion is that recollection deficits in ASD can be attributed to a difficulty engaging elaborative encoding (Meyer et al., 2014), known to disproportionately benefit subsequent recollection over and above familiarity (Yonelinas, 2002). Of note, adults with ASD show more pronounced recollection deficits under instructions to 'learn' rather than to 'forget' when these trial types are inter-mixed (Meyer et al., 2014), possibly suggesting a difficulty in engaging effective encoding strategies. Furthermore, subjects with ASD can show reduced recall of semantically-related words compared to unrelated words (e.g. Gaigg, Gardiner, & Bowler, 2008), and atypical inferior frontal gyrus function during memory encoding (Gaigg et al., 2015), a region that is involved in semantic and elaborative encoding (Otten, Henson, & Rugg, 2001). However, in the study by Meyer et al. (2014), it is unclear whether low levels of recollection of to-be-forgotten words in the control group as well as potential issues of cognitive and behavioural flexibility when switching between trial types may have contributed to the apparent reduction in elaborative encoding in ASD. The relationship between elaborative encoding and recollection deficits in ASD is therefore somewhat unclear.

Incidental encoding *versus* intentional encoding would provide an informative alternative test of an elaborative encoding deficit in ASD, having been used to test strategic encoding in older adults (e.g. Naveh-Benjamin et al., 2009). This task has the advantage of providing a direct comparison between a more 'natural' encoding situation (engaging bottom-up processes), which is rarely employed when investigating memory in ASD, and strategic learning (engaging more top-down control processes). Only one study to date has compared the effect of incidental and intentional encoding on recollection (source memory) in adolescents with ASD and, in contrast to Meyer et al. (2014), observed that both groups benefitted similarly from intentional encoding (Souchay, Wojcik, Williams, Crathern, & Clarke, 2013). However, there was no overall deficit in source memory in ASD and different source contexts were used for the two encoding tasks, meaning that one type of information could have simply been easier to remember. The current study thus aimed to test intentional encoding in comparison to incidental encoding using the same type of stimuli and test for both conditions to improve our understanding of elaborative encoding in ASD.

While the aforementioned evidence focuses on potential deficits in top-down control of memory encoding, there is also evidence in ASD that bottom-up processes might also function atypically, potentially revealed by investigating incidental encoding. Research has suggested that differences in natural patterns of attention (Ames & Fletcher-Watson, 2010) and perception (Happé & Frith, 2006; Mottron, Dawson, Soulières, Hubert, & Burack, 2006) exist in ASD and that such differences could contribute to memory deficits by altering the quality of memory experiences and limiting information that can be subsequently recollected (Loth, Carlos Gómez, & Happé, 2011). Specifically, some evidence suggests that people with ASD have enhanced perception of local features (Joseph, Keehn, Connolly, Wolfe, & Horowitz, 2009; Smith & Milne, 2009), and make fewer fixations that are more biased towards salient lower-level features than central objects or semantic features when viewing scenes (Heaton & Freeth, 2016; Wang et al., 2015). Conversely, other studies have revealed minimal differences between subjects with ASD and typical controls in their fixation patterns to complex scenes (Au-Yeung, Benson, Castelhano, & Rayner, 2011; Freeth, Foulsham, & Chapman, 2011). Furthermore, others have observed a similar or even an impaired ability to discriminate between stimuli varying in local features, including scenes (Au-Yeung et al., 2011; Fletcher-Watson et al., 2012; Loth, Carlos Gómez, & Happé, 2008) and objects (O'Hearn et al., 2014; Peiker et al., 2015). It therefore remains possible that differences in bottom-up attention and perception might contribute to memory impairments in ASD, but exactly what differences are present and how these might influence memory representations are unclear. Only one study to date has linked eye movements and memory in ASD, observing that these individuals were less likely to fixate objects related to the semantic context when viewing scenes, which was accompanied by reduced recall of these objects later on (Loth et al., 2011). This suggests that differences in fixation patterns at encoding in ASD might affect how well visual information can be recollected.

In the neurotypical population, research has increasingly used eye movements as a measure of encoding and an indirect measure of memory retrieval due to the additional information that cannot be ascertained from explicit memory responses (cf. Hannula et al., 2010). For instance, a greater number of fixations to visual stimuli during encoding is predictive of subsequent retrieval success on a trial-by-trial basis (Molitor, Ko, Hussey, & Ally, 2014; Pertzov, Avidan, & Zohary, 2009), suggesting that encoding-related fixations reflect an accumulation of evidence and a more deeply encoded memory representation. Similarly, with regard to recollection specifically, there is evidence that the degree to which fixations cluster (distance between fixations) during encoding can predict subsequent recollection success, compared to familiarity (Kafkas & Montaldi, 2011; Sharot, Davidson, Carson, & Phelps, 2008). However, whether more clustered or less clustered fixations predict recollection is likely dependent on the type of visual stimuli and task used; i.e. whether memory for a couple of specific details or many details of the image would improve memory. Measuring eye movements during encoding can also prove informative about the strategies participants are adopting and, thus, are well suited for identifying differences between incidental and intentional encoding (e.g. Shih, Meadmore, & Liversedge, 2012).

Eye movements during retrieval can also reveal a substantial amount of information about memory processes. A greater number of fixations during retrieval is thought to be indicative of identification of the correct response or novelty even when an incorrect explicit memory decision is made (Hannula & Ranganath, 2009; Molitor et al., 2014). In the study by Molitor and colleagues, participants made more fixations to a novel stimulus compared to a familiar stimulus even when they incorrectly identified the novel stimulus as familiar. Recollection has been observed to be associated with more distributed fixations during retrieval compared to familiarity (Kafkas & Montaldi, 2012) and there is also evidence that greater encoding-retrieval similarity in fixations, in terms of the proportion of retrieval eye movements that are directed towards areas attended to during encoding, predicts recollection rather than familiarity judgements (Holm & Mantyla, 2007). It is thought that this fixation 'reinstatement' possibly reflects configural memory of the studied stimulus (Ryals, Wang, Polnaszek, & Voss, 2015). Importantly, disrupting this perceptual reconstruction during retrieval has been shown to selectively impair recollection without affecting familiarity (Mantyla & Holm, 2006), suggesting that this process is directly associated with the likelihood of recollection success. Similarly, greater fixation reinstatement has been associated with more accurate memory and disrupting reinstatement reduces memory accuracy (Laeng, Bloem, D'ASDenzo, & Tommasi, 2014; Olsen, Chiew, Buchsbaum, & Ryan, 2014). Fixation reinstatement has been interpreted as a reconstruction of the memory representation (Laeng et al., 2014) and, thus, may shed light on the efficiency and quality of recollection in ASD and the relationship between encoding and retrieval.