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Behavioral and Eye-Movement Correlates of Item-Specific and Relational Memory in Autism

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BEHAVIORAL AND EYE-MOVEMENT CORRELATES OF ITEM-SPECIFIC AND
RELATIONAL MEMORY IN AUTISM

by

Greta N. Minor

A Dissertation Submitted in
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August 2023

ABSTRACT

BEHAVIORAL AND EYE-MOVEMENT CORRELATES OF ITEM-SPECIFIC AND RELATIONAL MEMORY IN AUTISM

by

Greta N. Minor

The University of Wisconsin-Milwaukee, 2023
Under the Supervision of Professor Deborah E. Hannula

Recent work has challenged past findings that documented relational memory impairments in autism. Previous studies have often relied solely on explicit behavioral responses to assess relational memory integrity, but successful performance on behavioral tasks may rely on other cognitive abilities (e.g., executive functioning) that are impaired in some autistic individuals. Eye-tracking tasks do not require explicit behavioral responses, and, further, eye movements provide an indirect measure of memory. The current study examined whether memory-specific viewing patterns toward scenes differ between autistic and non-autistic individuals. Using a long-term memory paradigm that equated for complexity between item and relational memory tasks, participants studied a series of scenes. Following the initial study phase, scenes were re-presented, accompanied by an orienting question that directed participants to attend to either features of an item (i.e., in the item condition) or spatial relationships between items (i.e., in the relational condition) that might be subsequently modified during test. At test, participants viewed scenes that were unchanged (i.e., repeated from study), scenes that underwent an “item” modification (an exemplar switch) or a “relational” modification (a location switch), and scenes that were never seen before. Eye movements were recorded throughout. There were no significant group differences in explicit recognition accuracy or the expression of eye-movement-based memory effects when scenes were intact, modified, or new. However,

differences in subjective memory confidence, the associations between study- and test-related memory indices, and the impact of external sample characteristics on retrieval-related eye movements suggest subtle dissociations in the quality of memory representations and/or in the relationships between subcomponents of memory in autism.

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Behavioral and Eye-Movement Correlates of Item-Specific and Relational Memory in Autism

Autism is a neurodevelopmental disorder characterized by persistent deficits in social interaction and social communication, in addition to the presence of restricted and repetitive behaviors, interests, or activities (American Psychiatric Association, 2013). According to the *Diagnostic Statistical Manual of Mental Disorders, 5th Edition* (DSM-5), impairments in social interaction and communication may appear in social-emotional reciprocity, in nonverbal social communicative behaviors, and in the understanding of social relationships. Restricted and repetitive behaviors may present as stereotyped movements or speech, rigid adherence to routine, fixated interests, or aberrant reactivity to sensory input. The functional consequences of autism often occur in social or occupational contexts, as many autistic individuals¹ show difficulty with forming relationships and with obtaining and maintaining employment (see Howlin & Magiati, 2017 for review). Notably, the level of impairment in adaptive behavior (i.e., self-sufficiency in daily living; Sparrow et al., 1984, p. 6) is heterogenous and depends on the severity of symptoms as well as the presence of commonly comorbid disorders (McCauley et al., 2020; see Lai et al., 2019 for review), such as intellectual disability (Fombonne, 2002), attention-deficit/hyperactivity disorder (Craig et al., 2015; Zablotzky et al., 2020), epilepsy (Tye et al., 2019), and anxiety/depression (Hollocks et al., 2017).

While it is true that the genetic and neurobiological underpinnings of autism have become increasingly defined over recent years (Amaral et al., 2008; Lyall et al., 2017; Minshew & Williams, 2007), an autism diagnosis is still made on the basis of the behavioral hallmarks

¹It is recognized that some individuals on the autism spectrum prefer identity-first language (i.e., autistic individual) relative to person-first language (i.e., individual with autism; Kenny et al., 2016). Thus, the present study will use identity-first language with the acknowledgement that this preference varies.

described above. These behavioral features, which are often the first identifiable symptoms of autism in early childhood (Landa & Garrett-Mayer, 2006; Landa et al., 2007; Yirmiya & Ozonoff, 2007), are thought to reflect underlying differences in cognitive functioning in autistic individuals relative to non-autistic individuals (Minshew & Williams, 2007). Specifically, it has been proposed that abnormalities in social cognition and sensory processing likely contribute to the pattern of observed behaviors in autism (e.g., Baron-Cohen et al., 1985; Frith, 1989; Minshew & Goldstein, 1998; Mottron & Burack, 2001; Pelphrey et al., 2011). Indeed, past research has documented atypical face processing strategies and an attenuation of spontaneous attention to social information (e.g., faces, gaze direction, biological-motion cues) in autism (e.g., Dawson et al., 1998; Elgar & Campbell, 2001; Klin et al., 2009; see Papagiannopoulou et al., 2014 for review). Independent of social cognition differences, basic cognitive processing differences have been observed in autism, including enhanced perceptual processing abilities (e.g., Mottron et al., 2000) and superior visual discrimination of novel stimuli (e.g., Plaisted et al., 1998).

Additional aspects of cognition, which are non-criterial for diagnosis, appear to be impacted in autism as well. For instance, deficits in executive functioning (e.g., inhibitory control, set shifting, conflict monitoring, cognitive control) and attention (e.g., selective attention, rapid attentional orienting, attentional disengagement) have been reliably reported (Belmonte & Yurgelun-Todd, 2003; Landry & Bryson, 2004; Mostert-Kerckhoffs et al., 2015; Solomon et al., 2008, 2009; Wainwright-Sharp & Bryson, 1993; see Demetriou et al., 2018; Lai et al., 2017 for review). Patterns of performance on episodic memory tasks have been atypical as well (see Boucher et al., 2012; Cooper & Simons, 2019; Desauvay, Briant, et al., 2020; Griffin et al., 2021 for review). For example, past work has often shown that memory for the central

component of an event (i.e., item memory) is relatively preserved in autistic persons, while memory for relationships between items and their contexts or inter-item associations (i.e., relational memory) is impaired in autistic individuals (e.g., Bigham et al., 2010; Bowler et al., 2014; Cooper, Richter, et al., 2017; Desaunay, Clochon, et al., 2020). Notably, however, recent studies have challenged this reported dissociation (e.g., Hogeveen et al., 2020; Justus et al., 2021; Ring et al., 2016; Solomon et al., 2016). While some inconsistent cognitive findings may be attributed to heterogeneity in the autistic clinical phenotype, it is possible that conflicting findings are also a consequence of differing task demands or task difficulty across previous studies. Specifically, much of the past work investigating episodic memory in autistic individuals has relied solely on explicit behavioral responses (e.g., button-press recognition responses). However, performances on behavioral tasks are susceptible to other forms of cognitive dysfunction (Luck & Gold, 2008) and may rely on additional cognitive faculties that are impaired in autistic individuals – for example, inhibitory control. Furthermore, past work has sometimes utilized incidental encoding tasks, which are likely more challenging for autistic individuals, who often show attentional difficulties, relative to their non-autistic peers. In this way, it is possible that previously reported memory “deficits” in autistic individuals may be a consequence of the conflated cognitive requirements of specific tasks that have been used rather than evidence for true memory impairments.

Other experimental methodologies, such as eye tracking, can be useful in disambiguating such possibilities. Eye-tracking tasks do not require explicit behavioral responses, rendering them powerful tools in cognitive investigations within clinical populations, such as autism, schizophrenia, amnesia, and mild cognitive impairment (Crutcher et al., 2009; Hannula, Ranganath, et al., 2010; Jones et al., 2008; Ryan & Cohen, 2004; Seligman & Giovannetti, 2015;

Smith & Squire, 2017; see Hannula, Althoff, et al., 2010 for review). Eye movements can provide an indirect measure of cognitive processes, such as attention and memory. In experimental paradigms examining differences in the exploration of visual stimuli, eye movements permit investigators to examine moment-to-moment changes in the focus of attention, assessing where individuals look and for how long (see van Zoest et al., 2017 for review). Additionally, past studies have shown that individuals automatically make eye movements toward modifications in previously studied materials, even when they are unable to explicitly report these changes (Ryan et al., 2000; Ryan & Cohen, 2004), and participants disproportionately view the associate of a previously studied stimulus (Hannula & Ranganath, 2009), even before explicit recognition responses are made (Hannula et al., 2007).

While eye tracking has been used to examine the exploration of social stimuli in autism (with differences in viewing patterns reported; see Chita-Tegmark, 2016; Papagiannopoulou et al., 2014 for review), few studies have used eye movements to investigate whether there are differences in viewing patterns to scenes that are not explicitly social (i.e., do not contain human figures) or to examine the integrity of memory in autism. The present study utilized an eye-tracking paradigm to determine whether memory-specific viewing patterns to computer-generated scenes differed between autistic and non-autistic individuals. In alignment with past work, we also collected behavioral recognition responses. In the sections that follow, an overview of episodic memory is provided, and an important distinction from the literature between item-specific and relational memory is described. As noted briefly above, this distinction is especially important in the current work, as it has been proposed that autism is marked by relational memory impairments and a relative sparing of item-specific memory (e.g.,

Bigham et al., 2010; Bowler et al., 2014; Cooper, Richter, et al., 2017; Desaunay, Clochon, et al., 2020).

Episodic Memory Depends on Relational Representations

Episodic memory, a subdivision of declarative memory (Squire, 1992; Tulving, 1972), refers to the processing system that supports memory for personally experienced events, acquired within a particular temporal and spatial context. For example, an individual's memory for their visit to Sacramento last summer constitutes an episodic memory because it was personally experienced by the individual recalling the details of the visit that occurred at a particular time (i.e., last summer) and place (i.e., Sacramento). Episodic memories are fundamentally relational, as episodic memory representations depend upon the flexible binding of inter-item and item-context relationships during encoding (i.e., learning; Cohen & Eichenbaum, 1993; Cohen et al., 1997; Eichenbaum & Cohen, 2014; Konkel & Cohen, 2009). Relational memory representations can support the experience of conscious *recollection*, which is defined as the recall of an item together with additional contextual detail about the encoding experience (e.g., corresponding scene details, the other object with which it was presented, thoughts that occurred when the item was initially seen; see Yonelinas, 2002; Yonelinas & Parks, 2007 for review). Relational memory can be contrasted with another form of episodic memory – item-specific memory – which represents memory for items in isolation of specific contextual details. Item-specific memory may result in a sense of *familiarity*, which is defined as the retrieval of an item in the absence of additional contextual details from the encoding experience (e.g., recognizing an image but being unable to identify where or when it was last seen). Of note, recollection and familiarity processes do not always map directly onto relational and item-specific memory (Yonelinas & Parks, 2007).

In non-autistic individuals, dissociable regions of the medial temporal lobes (MTL), including the hippocampus and perirhinal cortex, support item-specific and relational memory representations (Eichenbaum et al., 2007; Konkel & Cohen, 2009; Ranganath, 2010). Amnesic studies in humans have demonstrated that selective hippocampal damage leads to deficits in relational (e.g., inter-item, item-location, temporal order) memory and a relative preservation of item-specific memory (e.g., Cohen & Eichenbaum, 1993; Hannula et al., 2006, 2007; Konkel et al., 2008; Mayes et al., 2004; Ryan & Cohen, 2003; Ryan et al., 2000). Further, neuroimaging studies have also supported the role of the hippocampus in relational memory, as well as further characterized the role of the MTL subregions (see Rugg & Vilberg, 2013 for review). Evidence from functional imaging studies have demonstrated that encoding-related activation in the hippocampus is correlated with subsequent recognition of relational information and that encoding-related activation patterns in the perirhinal cortex are predictive of later item recognition (e.g., Davachi et al., 2003; Ranganath et al., 2004; Staresina & Davachi, 2008; Uncapher et al., 2006). Similar patterns have been observed during retrieval (e.g., Diana et al., 2010; Hannula et al., 2013). For example, hippocampal activation at retrieval co-varies with the number of contextual details recalled about a learning episode, suggesting that relational memory depends critically on the hippocampus (see Rugg & Vilberg, 2013 for review).

More broadly, neuroimaging studies, conducted with non-autistic individuals, have also indicated that structures in the frontal and parietal lobes make important contributions to episodic memory encoding and retrieval (see Kim, 2010; Spaniol et al., 2009 for review). For example, the prefrontal cortex (PFC) is thought to support the cognitive control of episodic memory (see Badre & Wagner, 2007; Blumenfeld & Ranganath, 2007; Spaniol et al., 2009 for review). Specifically, the ventrolateral PFC has been linked to the controlled retrieval of domain-specific

information and to the post-retrieval selection of goal-relevant information (e.g., Dobbins & Wagner, 2005). During encoding, the dorsolateral PFC is hypothesized to support episodic memory by enabling the spontaneous organization of items and their associations within working memory (e.g., see Blumenfeld & Ranganath, 2007 for review) and, during retrieval, is thought to play a role in ‘source monitoring,’ a process in which the product of a memory search is verified (see Fletcher & Henson, 2001 for review). Furthermore, the medial PFC is thought to be involved in self-referential processing, metacognition, and mental simulation (i.e., “self-projection”), processes which likely contribute to the integration of retrieved memories with prior knowledge (e.g., Preston & Eichenbaum, 2013; Schlichting & Preston, 2015).

In a complementary fashion, activation within the posterior parietal cortex (PPC) has been associated with the subjective experience of recollection (see Moscovitch et al., 2016; Rugg & Vilberg, 2013 for review). Patients with parietal lobe lesions tend to exhibit an impaired ability to initiate recall of autobiographical memories (e.g., Berryhill et al., 2007) and show reduced recollection-related responses and high confidence source memory judgments (e.g., Ciaramelli et al., 2017; Davidson et al., 2008; Drowos et al., 2010). Additionally, the PPC is thought to contribute to the online representation and maintenance of retrieved representations over time (e.g., Kuhl & Chun, 2014; Vilberg & Rugg, 2012), as the successful recollection of specific details of a learning episode elicits increased activation in this region (e.g., Dobbins & Wagner, 2005; Spaniol et al., 2009; Wagner et al., 2005). Other accounts highlight the role of the angular gyrus of the posterior parietal cortex in directing attentional resources to retrieved content (e.g., Cabeza et al., 2008) and in mnemonic evidence-gathering and decision-making (e.g., Wagner et al., 2005). Taken together, interactions between frontal/parietal regions and the

medial temporal lobes appear to support the successful encoding and retrieval of episodic information.

Inconsistent Patterns of Item-Specific and Relational Memory Performance in Autism

The potential for episodic memory deficits in autism is not unwarranted, as there are documented structural and functional connectivity differences in brain regions that contribute to episodic memory. For example, structural abnormalities in the hippocampus and volumetric differences in frontal and parietal brain regions have been reported in postmortem and structural imaging studies with autistic individuals (Bauman & Kemper, 2005; Ecker et al., 2010; Fetit et al., 2021; although see Trontel et al., 2015). Furthermore, functional neuroimaging studies suggest that there are abnormalities in functional connectivity between the PFC, parietal regions, and hippocampus in autistic individuals (e.g., Banker et al., 2021; Barnea-Goraly et al., 2014; Ben Shalom, 2003; Boucher & Mayes, 2012; Cooper, Richter, et al., 2017; Li et al., 2022). For example, attenuated functional connectivity between the hippocampus and fronto-parietal networks has been reported during retrieval, accompanied by lower retrieval accuracy, in autistic individuals (Cooper, Richter, et al., 2017), and another study has documented reduced activation in the left posterior hippocampus and enhanced PFC activation during encoding, which may indicate that encoding is more effortful for autistic persons (Gaigg et al., 2015).

These structural and functional differences in autism appear to confirm reported deficits on episodic memory tasks that require retrieval of details diagnostic of the encoding experience (Boucher, 1981; Boucher & Warrington, 1976; Bowler et al., 1997). Indeed, though early accounts suggested that memory may be a relative strength given the “excellent rote memory” observed in autistic children (Kanner, 1943, p. 243), later work reported consistent memory deficits on recall-related tasks in autism (Boucher, 1981; Boucher & Warrington, 1976; Bowler

et al., 1997). One theoretical explanation for these findings emphasizes impairment in the subjective “re-experiencing” component of episodic memory retrieval, or *autonoetic awareness* (Tulving, 1985b), in autism. Much like the parietal lobe patient studies described above, prior work suggests that autistic individuals show reductions in subjective, recollection-related responses (i.e., “remember” responses in remember-know paradigms; e.g., Bowler et al., 2007; Cooper et al., 2015), judgments of mnemonic accuracy (i.e., metamemory; e.g., Cooper et al., 2016; Grainger et al., 2014; Wojcik et al., 2013), and recall of autobiographical memories (e.g., Lind & Bowler, 2010). However, evidence of deficits in the subjective experience of recollection in autism has been mixed (e.g., Grainger et al., 2016; Wojcik et al., 2014), and it remains possible that other aspects of executive dysfunction (e.g., weaknesses in strategic retrieval or cognitive control; Solomon et al., 2016) may contribute to such findings.

Additionally, subsequent studies investigating the representational content of episodic retrieval impairments in autism report patterns of episodic memory performance that are not easily accommodated by the subjective recollection deficit hypothesis. For example, several studies have documented relational memory impairments accompanied by intact item-specific memory at retrieval (e.g., Bigham et al., 2010; Bowler et al., 2014; Desaunay, Clochon, et al., 2020). In one illustrative study, Bowler and colleagues (2014) instructed participants to study grids containing everyday objects in non-canonical colors. In a first experiment, to assess recognition for single features, participants were directed to attend to an object, the color of an object, or the location of an object in the grid. Recognition performance across conditions was equivalent between autistic and non-autistic adults, suggesting that memory for single features is preserved in autistic individuals. Memory for a combinations of features was measured in a second experiment, in which participants were instructed to attend to either object-location or

object-color features together. Autistic adults exhibited significantly lower memory performance across both conditions relative to their non-autistic counterparts, taken as evidence for a selective deficit in relational memory in autism. Relational memory deficits have also been documented with the use of other types of stimuli, including abstract shapes, and across different types of relational memory tasks, assessing memory for inter-object, object-action, and object-voice pairings (Bigham et al., 2010; Cooper, Richter, et al., 2017; Desautay, Clochon, et al., 2020; Lind & Bowler, 2009). Such findings are in line with a memory-specific theory of cognition in autism referred to as the *relational binding account* (Bowler et al., 2011), which posits that autistic individuals show a selective deficit in the hippocampal-mediated binding of items and contexts but a relative sparing of memory for items alone.

Importantly, however, the relational binding account has not always been supported by previous findings. For instance, other studies have reported that autistic individuals show deficits restricted to item memory (Cooper, Plaisted-Grant, et al., 2017; Solomon et al., 2016), impairments in both item and relational memory (Cooper et al., 2015; Massand & Bowler, 2015; Mogensen et al., 2020; Ring et al., 2016; Semino et al., 2018), or intact item and relational memory (Hogeveen et al., 2020; Lind et al., 2014; Ring et al., 2015, 2017; Souchay et al., 2013). One possible explanation for disparate findings is that task complexity has differed across item-specific and relational memory tasks utilized in previous studies (e.g., Bowler et al., 2014). Indeed, past work has often measured item-specific memory by requiring participants to recognize a single item from the encoding phase, while relational memory has frequently been assessed with tasks that require participants to remember multiple elements of the encoding scenario. Further supporting the potential effects of this confound in prior work, autistic individuals have shown impairments in the processing of “complex” information (e.g., complex

conceptual structure/organization of material and/or retrieval tasks that require higher levels of cognitive control) across different cognitive tasks (*complex information processing model*; Minschew & Goldstein, 1998, 2001). Thus, it is conceivable that reports from previous studies may conflict due to differences in task demands between item-specific and relational memory tasks.

To address this shortcoming of previous work, Cooper and colleagues (2015) utilized a long-term memory task that equated complexity between the item-specific and relational memory experimental conditions. During an encoding phase, autistic and non-autistic adults studied computer-generated indoor and outdoor scenes that contained pre-defined “critical” items. One third of the studied scenes were assigned to the ‘item’ condition (i.e., the critical item in the scene was replaced with a different exemplar at test), one third of the scenes were assigned to the ‘relational’ condition (i.e., the critical item changed spatial locations at test), and one third of the scenes were assigned to the ‘repeated’ condition (i.e., the same scene was viewed during study and test). During the subsequent test phase, participants were instructed to identify whether a presented scene had undergone an item or relational change, had not changed (i.e., ‘repeated’ scenes), or was new (i.e., a scene that had not previously been studied; ‘novel’ scenes).

Additionally, to examine whether deficits in subjective recollection might be driving previous reports of memory impairment in autism (e.g., Bowler et al., 2000; Bowler et al., 2007; Souchay et al., 2013), participants were asked to identify the specific item or spatial location that had changed (for scenes identified as having undergone an item or relational change) and to indicate whether they were able to consciously remember the original appearance of the scene (for scenes identified as repeated) during test in a modified remember-know procedure (Tulving, 1985a). Importantly, the experiment was designed such that memory for item-specific detail and spatial

relationships was assessed in the context of the same set of scenes, and pilot testing confirmed that performance was well-matched across conditions (Hannula et al., 2015).

Corrected recognition scores for scenes (i.e., novel scenes correctly identified as “new” – novel scenes incorrectly identified as “old”) were near ceiling in both groups, though there was a trend for slightly better scene discrimination in the non-autistic participants relative to the autistic participants (Cooper et al., 2015). Group differences in performance emerged when comparing correct identification of item and relational changes in scenes; the autistic group correctly identified significantly fewer item and relational changes as compared to their non-autistic counterparts, suggestive of a potential deficit across both item-specific and relational memory in autistic individuals. Additionally, to examine the contribution of subjective recollection to recognition performance, corrected “remember” responses (i.e., “remember” hits – “remember” false alarms) were calculated for each scene type. Autistic individuals made significantly fewer recollection-based responses to correctly identified item scenes and repeated scenes and marginally fewer recollection-based responses to correctly identified relational scenes relative to their non-autistic counterparts, possibly indicating that autistic individuals rely less on recollection-based processes during retrieval than non-autistic individuals. Together, these findings suggest that, when item-specific and relational memory tasks are equated in their complexity, autistic individuals may show relative deficits in both item-specific and relational memory processes as compared to their non-autistic peers. However, another possibility is that the item memory impairment reported by Cooper and colleagues (2015) may have simply been a consequence of the encoding context. Items were embedded within complex scenes, and memory for the items may have benefitted from the binding of the items to other elements within the

scene in non-autistic individuals, thus leading to an apparent item-specific memory deficit in the autistic group.

As mentioned above, much of the previous work in this domain, including Cooper et al.'s (2015) study, has relied on explicit recognition tasks, and successful performance on these tasks may rely on other cognitive abilities that may be impaired in autistic individuals (e.g., inhibitory control; Schmitt et al., 2018; see Tonizzi et al., 2021 for review). Moreover, other aspects of behavioral tasks, such as relatively uncontrolled encoding conditions, have made it difficult to determine whether observed results provide evidence of true memory deficits or represent consequences of attentional and executive processing difficulties during encoding. For example, in Cooper et al.'s (2015) work, participants were instructed to try and remember the appearance and location of the objects in the scene. However, autistic individuals show deficits in the disengagement of attention (see Keehn et al., 2013 for review) and inefficient attentional filtering of information (e.g., Burack, 1994; Keehn et al., 2019; Murphy et al., 2014), impairments that may have interfered with the initial exploration and encoding of information in scenes during the study phase and led to reported "memory deficits." In sum, specific task requirements may result in the conflation of cognitive processes that are differentially preserved or impaired in autism, and these differences may account for reported discrepancies in the performance of autistic individuals on tests of episodic memory.

It is in this context that other methods, which are less reliant on higher-order cognitive abilities, may be useful in disentangling contradictory findings. In an initial attempt to examine whether differences may arise in performance on a direct memory task versus indirect memory task, a behavioral study by Ring and colleagues (2015) manipulated task demands at retrieval. During an encoding phase, participants viewed pictures of rooms with context-appropriate

objects presented beneath the images. A region within each image was highlighted, and participants were required to place the object in the highlighted location in the room. During a subsequent test phase, they were presented with three highlighted locations in a previously studied room with both the “old” (i.e., previously studied) object and two new objects pictured below the image. On *direct* memory trials, participants were instructed to recall the location of the previously studied object during study and place it in the same location at test. On *indirect* memory trials, participants were required to place the previously studied object in a new location in the room, a task which necessitates retrieval of the “old” location first. Finally, participants completed a recognition and source memory task for items and locations. In the object recognition task, they were presented with either a studied or novel object and asked whether they had seen the object before. If they indicated that the object was previously seen, they were asked to recall its location during encoding. During the location recognition task, participants were presented with highlighted locations in scenes viewed during encoding; $\frac{3}{4}$ of the highlighted regions were previously filled during encoding and the remaining $\frac{1}{4}$ were new regions. Again, if participants responded that a location was highlighted earlier during the task, they were asked to indicate which object had been presented with that location. Item-specific memory was defined as recognition of the objects themselves, whereas relational (i.e., source) memory was defined as recognition of the highlighted locations during encoding.

Performance on direct memory trials (i.e., direct retrieval of object locations) was significantly lower in the autistic group relative to the non-autistic group, but performance on indirect memory trials (i.e., indirect retrieval of object locations) was equivalent between groups, supporting the possibility that direct retrieval as compared to indirect retrieval of relational memories may be disproportionately challenging for autistic individuals (Ring et al., 2015).

Furthermore, item and source recognition for objects and locations was comparable across groups, suggesting that retrieval support provided during a recognition task may attenuate relational memory impairments seen on retrieval tasks with higher task demands, such as the direct memory task (*task support hypothesis*; Bowler et al., 2004; Bowler et al., 1997; Gaigg et al., 2008; cf. Griffin et al., 2021). Thus, studies that employ more indirect measures of memory may provide a more nuanced account of relational memory processes in autism.

Eye Movements Provide an Indirect Index of Memory

Eye tracking has been a useful tool for indirect (or implicit) measurement of memory. For instance, seminal work suggested that eye movements are sensitive to well-learned semantic associations (Loftus & Mackworth, 1978). In this study, eye movements were made more rapidly to objects that were incongruent with the scene context in which they were embedded than to a corresponding congruent object (e.g., an octopus versus a cow in a barnyard, respectively). Subsequent studies have shown that eye movements are sensitive to episodic memory as well, including repeated exposures to a stimulus. When a stimulus is repeated, participants make fewer fixations and sample fewer distinct regions of a picture with each repetition (i.e., termed the repetition effect; Althoff & Cohen, 1999; Heisz & Shore, 2008; Ryan et al., 2000; Ryan et al., 2007). Additionally, it has been reported that the number of fixations made during encoding correlates with overall recognition accuracy during test (Molitor et al., 2014; Olsen et al., 2016; Pertzov et al., 2009).

During retrieval, viewing patterns also distinguish between previously studied scenes that have been modified from those that are repeated without a change (Hannula, Ranganath, et al., 2010; Ryan & Cohen, 2004). In one representative example, Hannula and colleagues (2010) used the task that was subsequently adopted by Cooper et al. (2015) but also incorporated a second,

controlled encoding phase. Participants viewed rendered indoor and outdoor scenes, containing a pre-defined “critical” item, during an initial encoding phase (as described above; Cooper et al., 2015). This time, in a second study phase that directly followed the first, participants viewed the same set of scenes, but now each scene was also accompanied by an orally-presented “yes/no” question that oriented participants to either the features of an item (i.e., an ‘item’ orienting question) or the spatial location of an item (i.e., a ‘relational’ orienting question) that might be subsequently modified during test. At test, as in Cooper et al.’s (2015) study, participants were instructed to identify whether a scene had undergone an item or relational change, had not undergone a change, or was a new scene. Scenes at test were yoked, such that three participants saw the exact same version of the scene during test, but differential encoding histories rendered the scene either modified (i.e., having undergone an item or relational change), repeated, or novel. Therefore, differences in viewing patterns at test were attributable to differences in viewing histories, rather than differences in scene features.

For scenes that were assigned to the item condition, viewing directed to the region of the scene containing the critical item (i.e., ‘filled’ during test) was examined during the test phase (Hannula, Ranganath, et al., 2010). For scenes that were assigned to the relational condition, viewing directed to *two* regions of the scene during the test phase was considered. The first region corresponded to the location of the critical item during test (i.e., ‘filled’ during test), and the second region corresponded to the location of the critical item during study (i.e., ‘empty’ during test). Furthermore, two eye-movement-based measures of memory, termed *memory for repetition* and *memory for detail*, were examined separately for scenes assigned to the item and relational conditions. *Memory for repetition* was defined as the difference in proportion of total viewing time of the critical region(s) between repeated scenes and novel scenes. Participants

spent more time fixating the critical regions of the repeated scenes relative to analogous regions of the novel scenes, as expected, since their attention had been previously drawn to these regions by the orienting questions during the second encoding phase. *Memory for detail* was operationalized as the difference in proportion of total viewing time directed to the critical region(s) between modified scenes (i.e., scenes in the item or relational condition) and repeated scenes. In this case, participants spent a disproportionate amount of time viewing critical regions of modified scenes relative to repeated scenes, and participants even disproportionately viewed the *empty* region of scenes that underwent a relational manipulation, where an object had appeared during study, relative to corresponding regions in repeated scenes. Since eye movements are more likely to be made toward objects and not empty regions of a scene (Yarbus, 1967), these viewing time differences are most logically due to participant's memory for spatial relationships within the scene.

Further evidence for the sensitivity of eye movements to item-specific and relational memory manipulations comes from previous work with clinical populations. In the study described above (Hannula, Ranganath, et al., 2010), individuals diagnosed with schizophrenia showed a specific pattern of deficits in the memory for detail metric. Specifically, eye movement analysis revealed an attenuated eye-movement-based memory effect for scenes in the item condition as well as a *disproportionate* relational memory impairment in individuals with schizophrenia as compared to individuals in the control group. In other work, similar patterns have been documented with amnesic individuals; patients with selective damage to the hippocampus showed standard eye-movement-based memory effects for individual items but demonstrated deficits in relational memory eye movements (Althoff et al., 1993; Hannula et al.,

2007; Ryan et al., 2000). Based on these findings, it is reasonable to assume that eye movements may prove useful in the characterization of item-specific and relational memory in autism.

Only a handful of previous studies have employed eye-tracking tasks to address questions about the integrity of episodic memory in autism (Cooper, Plaisted-Grant, et al., 2017; Loth et al., 2011; Ring et al., 2017). An additional advantage of this method is that eye movements can be recorded throughout an experiment, which may permit researchers to pinpoint when (i.e., at what stage of processing – encoding vs. retrieval) memory deficits arise. Across different sets of materials and tasks (Cooper, Plaisted-Grant, et al., 2017; Loth et al., 2011), eye-tracking studies have reported equivalent viewing patterns (e.g., in gaze time, number of fixations, and fixation duration) between autistic and non-autistic individuals during encoding, possibly suggesting that attention to scenes during encoding is similar across autistic and non-autistic individuals. However, when correlated with subsequent memory success, previous work has suggested that encoding-related viewing may not be as predictive of subsequently remembered versus forgotten materials in autistic participants as it is in non-autistic participants (Cooper, Plaisted-Grant, et al., 2017; Loth et al., 2011; Ring et al., 2017). In contrast, past work that has measured retrieval-related viewing patterns finds that fixation ‘reinstatement’ (i.e., the extent to which viewing patterns from study are reinstated during test) is reduced for recollected scenes in autistic participants relative to non-autistic participants (Cooper, Plaisted-Grant, et al., 2017), potentially indicating that memory impairments in autism might be partially due to disrupted retrieval processes (cf. Griffin et al., 2021).

To our knowledge, only one eye-tracking study has used an item-specific and relational memory task (Ring et al., 2017), and results revealed differences in retrieval-related eye movements between groups. Using the task described above (Ring et al., 2015), participants

were required to either place a previously studied object in the same location in a scene in which it appeared during study (on *direct* memory trials) or to place a previously studied object in a new location (on *indirect* memory trials). Behaviorally, performance on the indirect memory trials was commensurate between autistic and non-autistic adults, but performance on the direct memory trials was lower for the autistic individuals. At retrieval, autistic adults spent less time viewing relevant areas of the scenes as compared to non-autistic individuals. Specifically, the autistic group spent less time fixating the target locations (i.e., previously studied object locations) on *direct* trials (i.e., when asked to place the object in the previously studied target location) as well as less time fixating the distractor locations (i.e., new object locations) on *indirect* trials (i.e., when asked to place the object in a new location), suggesting that impairments in object-location memory in behavioral responses may also be observed in retrieval-related viewing patterns at test for autistic individuals.

In summary, eye-tracking tasks have often been underutilized in episodic memory investigations in autism. Only one study investigating item-specific and relational memory has explored viewing patterns across an experimental session, and this work suggests that eye movements during retrieval may be sensitive to memory impairments evident in explicit responses in autism (Ring et al., 2017). In an important departure from previous studies, here we used a paradigm that specifically equated task difficulty across item and relational conditions (i.e., Cooper et al., 2015; Hannula, Ranganath, et al., 2010) to ensure that viewing effects could not be attributed to differential complexity of tasks, and direct (i.e., explicit response) and indirect (i.e., eye movement) measures of memory were compared across autistic and non-autistic groups.

The Current Study

We examined whether memory-specific viewing patterns toward realistic, non-social scenes differed between autistic and non-autistic individuals. Using a paradigm that equated for complexity between item and relational memory tasks (Cooper et al., 2015; Hannula, Ranganath, et al., 2010), participants first viewed a series of scenes while being instructed to memorize the scene. Following the initial study phase, scenes were re-presented, accompanied by an orienting question (e.g., “Is the hat on the chair?”). Participants were told to respond to the question, which was intended to encourage participants to fixate specific objects in the scenes that might be subsequently manipulated (i.e., exchanged with a different exemplar or moved to a different spatial location) during the test phase. During test, participants viewed scenes that were unchanged (i.e., repeated from study), scenes that underwent an “item” modification (an exemplar switch) or a “relational” modification (a location switch), and scenes that were never seen before. Both direct and indirect measures of memory were recorded.

Based on a previous study that used a similar task (Cooper et al., 2015), we hypothesized that both item-specific and relational memory performance on an explicit memory task may be impaired in the autistic group. However, since the use of an orienting question during the second study phase required participants to attend to and process critical objects in the scenes in order to respond accurately, it was possible that explicit memory performance may be at least partially recovered in the autistic group in the current study. Indeed, past work has shown that encoding conditions which encourage the explicit processing of relational (and item-specific) information can potentially mitigate memory performance impairments in autism (Bowler et al., 2010; Gaigg et al., 2008). Though there are limited studies examining eye movements in episodic memory tasks in autism, we predicted that encoding-related eye movements to critical regions of the

scenes would not differ between the autistic and non-autistic groups, consistent with past findings (Cooper, Plaisted-Grant, et al., 2017; Loth et al., 2011; Ring et al., 2017). However, we expected that encoding-related eye movements may show diminished correlations between subsequent memory performance and/or retrieval-related eye movements in autistic individuals (Cooper, Plaisted-Grant, et al., 2017; Loth et al., 2011; Ring et al., 2017). Eye-movement-based relational memory effects (i.e., disproportionate viewing directed to locations where spatial relationships changed) were expected to be reduced or absent in the autistic group, consistent with the relational binding hypothesis (Bowler et al., 2011) and as suggested by a previous eye-tracking study (Ring et al., 2017). Nonetheless, group differences in retrieval-related eye movements may be minimized due to the additional encoding manipulation in the current study, which would suggest that past findings may have been due to differences in attentional processing of the stimuli during encoding. The use of multiple measures (i.e., direct recognition responses, indirect eye-movement-based memory effects), together with well-matched tests of item-specific and relational memory, was expected to aid in disambiguating contradictory findings reported in the autism episodic memory literature (e.g., Bigham et al., 2010; Bowler et al., 2014; Cooper, Richter, et al., 2017; Desaunay, Clochon, et al., 2020; Hogeveen et al., 2020; Justus et al., 2021; Ring et al., 2016; Solomon et al., 2016).

Method

Participants

Forty participants (18 autistic, 22 non-autistic) were recruited during the second wave of data collection from an ongoing cohort-sequential study (*Neurodevelopment of cognitive control in autism: adolescence to young adulthood*; 1R01MH106518) of autistic and non-autistic persons without intellectual disability ($IQ \geq 70$) through the UC Davis MIND Institute and

Imaging Research Center. R (v4.1.2; package pwr) was used to estimate the number of participants needed for sufficient power to detect differences between conditions; this was done using data from a previously published investigation that was best matched to the current study (i.e., Cooper et al., 2015). The final sample size in the published study was 48 (24 autistic participants and 24 comparison participants). Cooper et al. (2015) reported a significant group difference in the relational memory condition, with an effect size (Cohen's *d*) equal to .64. Using this effect size, a minimum sample size of 11 participants per group was required to achieve power equal to .8 (with alpha set to .05, two-tailed).

Written, informed consent was obtained from participants in accordance with the UC Davis Institutional Review Board, and participants received a \$100 gift card for their participation. To be included in the study, all participants were required to be between the ages of 12 and 24 and to have a Full Scale IQ of 70 or above on the Wechsler Abbreviated Scale of Intelligence – 2nd Edition (WASI-II; Wechsler, 2011). Participants were not permitted to be taking psychotropic medications at the time of their enrollment in the study. Participants were also excluded from participation in the study if they had a diagnosis of epilepsy or another neurological disorder and/or if imaging was contraindicated. Autistic participants were required to have a community diagnosis of autism spectrum disorder (ASD) and were required to meet criteria for ASD on the DSM-5 Criteria Checklist for ASD (American Psychiatric Association, 2013) and Autism Diagnostic Observation Schedule – 2nd Edition (ADOS-2; Lord et al., 2000), which were administered by a licensed clinician at the UC Davis MIND Institute. Non-autistic participants were not included in the study if they had a community diagnosis of ASD, attention-deficit/hyperactivity disorder (ADHD), or any neurodevelopmental disorder, had a first-degree family member with ASD, had reported Axis I psychopathology, or surpassed a cut-off value of

11 on the Social Communication Questionnaire (SCQ; Rutter et al., 2003), suggestive of an autism diagnosis.

Table 1 provides basic descriptive statistics for each group on the following characteristics: gender, chronological age, WASI-II (Wechsler, 2011) Full Scale IQ (FSIQ-4), and WASI-II index scores (Verbal Comprehension Index [VCI] and Perceptual Reasoning Index [PRI]). There were no significant differences between groups on age, WASI-II FSIQ-4, or WASI-II index scores, F 's ≤ 1.69 , p 's $\geq .20$. In Table 1, scores on the semi-structured ADOS-2 (Lord et al., 2000) are also provided for individuals in the autistic group, including the calibrated severity score (CSS) and severity scores in the Social Affect (SA) and Restricted, Repetitive Behavior (RRB) domains.

Table 1
Demographic Characteristics of Sample

	Autistic (n=18)	Non-Autistic (n=22)
Female	7 (39%)	5 (23%)
Male	11 (61%)	17 (77%)
Age	20.68 (2.71; 16.42–24.83)	20.85 (2.68; 15.33–24.92)
FSIQ-4	103.11 (12.22; 76–125)	108.22 (13.58; 79–129)
VCI	102.61 (10.42; 85–120)	104.86 (15.18; 73–137)
PRI	103.11 (16.57; 68–131)	109.40 (14.07; 83–140)
ADOS CSS	7.06 (2.10; 4–10)	--
ADOS SA Severity	7.33 (2.00; 3–10)	--
ADOS RRB Severity	6.5 (2.94; 1–10)	--

Note. For categorical variables, frequencies (percentages) are reported. For continuous variables, means (standard deviations; ranges) are reported.

Table 2 presents scores on select tests from the NIH Toolbox® Cognition Battery that assessed symptoms related to inattention/impulsivity, executive dysfunction, working memory, and processing speed (Akshoomoff et al., 2013), including scores on the Flanker Inhibitory Control and Attention Test (FICA), Dimensional Change Card Sort Test (DCCS), Picture Sequence Memory Test (PSM), and List Sorting Working Memory Test (LSWM). There were significant differences between groups on two executive functioning tasks (FICA, DCCS), Welch’s $F \geq 5.95$, p ’s $\leq .013$, Glass’s $\Delta \geq 1.29$, and on an episodic memory test (PSM), $F(1, 38) = 7.01$, $p = .012$, $\eta_p^2 = .16$, with higher scores in the non-autistic group compared to the autistic group across all three measures. There were no significant group differences on a working memory task (LSWM), $F(1, 38) = .91$, $p = .35$.

Table 2
NIH Toolbox® Cognition Battery Scores for Sample

	Autistic (n=18)	Non-Autistic (n=22)
Flanker Inhibitory Control and Attention Test (FICA)*	103.89 (8.17; 90-114)	110 (5.1; 97-117)
Dimensional Change Card Sort Test (DCCS)*	105.11 (12.12; 81-120)	112 (5.91; 103-120)
Picture Sequence Memory Test (PSM)*	107.17 (11.25; 86-123)	118.14 (14.32; 95-136)
List Sorting Working Memory Test (LSWM)	110.06 (12.29; 90-136)	113.23 (8.70; 97-128)

Note. Means (standard deviations; ranges) are reported.

* $p < .05$

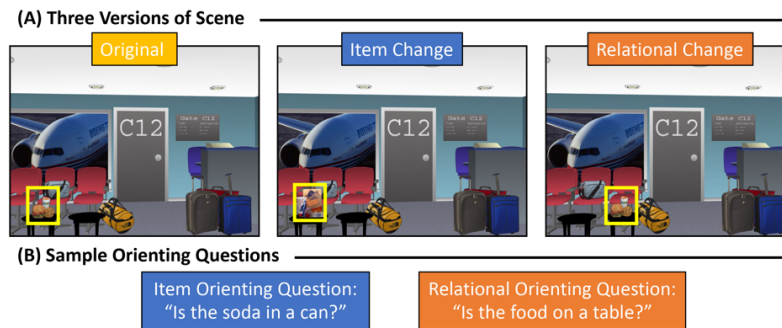
Materials and Apparatus

Sixty-four computer-generated indoor and outdoor scenes (800 x 600 pixels) created using Punch! Home Design Software (Encore, Inc., El Segundo, CA) by Hannula and colleagues (Hannula, Ranganath, et al., 2010; Hannula et al., 2006) were used in the current study. Three versions of each scene were developed – an original version, a version in which a designated critical item was switched with a different exemplar (i.e., an item manipulation), and a version in which that same critical item had been moved to a similarly plausible location (i.e., a relational manipulation; see Figure 1A). Thus, the total stimulus sample included 192 scenes. When critical objects switched spatial locations in the ‘relational’ condition, objects were moved equally often from left, in the original scene, to right, in the manipulated scene, and vice versa. Scenes were presented at a resolution set to 1,012 x 762 pixels, and scenes subtended 28.61 (width) by 21.74 (height) degrees of visual angle, from a viewing distance of 70 cm. Scenes were displayed on a monitor with 1,980 x 1,200-pixel resolution and a refresh rate of 60 Hz. Additionally, two orienting questions were created for each scene. One question was designed to orient the participant’s attention to the features of a critical object and the other to the spatial relationship between a critical object and its surroundings (examples are provided in Figure 1B). The purpose of the orienting question was to direct the viewer’s attention to critical items in the scenes that might be manipulated during the subsequent test block.

Eye movements were recorded with an Eyelink 1000 Plus eye-tracking system (SR Research LTD: Ontario, Canada). This system has a temporal resolution of 1000 Hz and head-supported spatial resolution of .01°. Eye movements were identified as saccades using an automated algorithm that requires a minimum velocity of 30°/s and a minimum acceleration of 8000°/s². The Experiment Builder software package (SR Research LTD: Ontario, Canada) was

used to deliver stimuli and the Data Viewer software package (SR Research LTD: Ontario, Canada) was used to extract the eye-tracking data.

Figure 1
Example Scenes and Orienting Questions



Note. (A) Example of three versions of a representative scene – the original scene, the version of that scene with an item manipulation, and the version of that scene with a relational manipulation. (B) Item (in blue) and relational (in orange) orienting question for the scene shown above (A).

Design and Procedure

After participants gave their consent to participate, they were seated 70 cm from the computer monitor and a chinrest was adjusted to a comfortable position. An automated 9-point calibration process was then performed to align fixation with screen coordinates before the experiment began; this process was repeated as necessary until calibration was successful and a drift correction procedure was used before each trial to ensure accurate tracking throughout the experiment. Prior to completing the experiment, instructions were provided, and participants completed practice trials related to each phase of the experiment (i.e., Study Block 1, Study Block 2, and Test Block). Twelve practice study trials (six each in Study Blocks 1 and 2) and eight practice test trials were used to ensure that participants understood the task. During the practice test trials, participants were given feedback on their performance. Scenes viewed during

study and test were presented side-by-side to afford participants the opportunity to become familiar with the types of scene manipulations they may encounter. Eye movements were recorded in each phase of the experiment.

Study Block 1

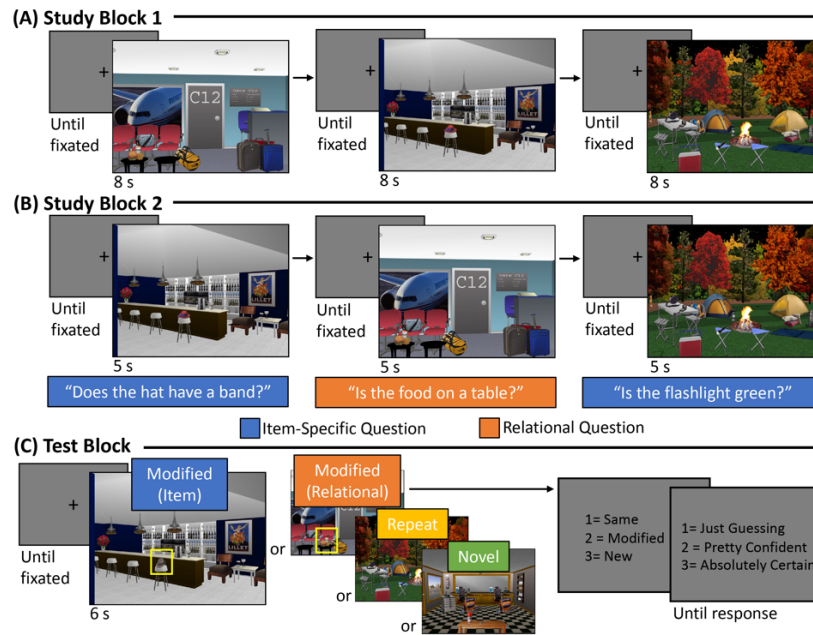
Following practice, participants were shown 48 scenes during Study Block 1 (see Figure 2A). Sixteen of these scenes were ‘repeated’ during test (i.e., the same version of the scene was re-presented), 16 underwent an item manipulation at test (i.e., henceforth referred to as the ‘item’ condition), and 16 underwent a relational manipulation at test (i.e., henceforth referred to as the ‘relational’ condition). Participants were instructed to view the scenes and to attempt to commit each scene to memory. Every trial began with a central fixation cross; the trial could not be initiated by the experimenter until the participant fixated the center of the screen. Each scene was presented for a duration of 8 s.

Study Block 2

During Study Block 2, the same 48 scenes were presented again in a new random order (see Figure 2B). When participants fixated the center of the screen, the experimenter initiated the trial, and a scene was presented for 5 s. Now, each scene was accompanied by a corresponding orienting question (pre-recorded and presented over speakers) that was initiated 500 ms after scene onset. The question directed the participant’s attention either to the features of a critical object (if the scene was assigned to the ‘item’ condition) or to the spatial relationship between a critical object and its surroundings (if the scene was assigned to the ‘relational’ condition). For scenes assigned to the ‘repeated’ condition, half were presented with an item-specific orienting question and half were presented with a relational orienting question. Participants were

instructed to respond “yes,” “no,” or “don’t know” to the orienting question via a button press, while the picture was in view.

Figure 2
Trial Structure and Event Timing



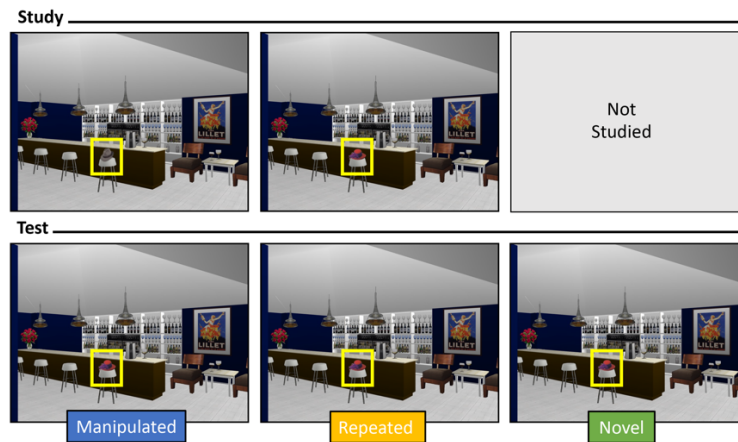
Note. (A) During Study Block 1, central fixation was followed by a scene (8 s). (B) During Study Block 2, central fixation was followed by a scene (5 s), accompanied by an orally-presented orienting question to which participants responded via button press. (C) During the Test Block, central fixation was followed by a scene (6 s). Participants indicated via button press whether the scene was the “same,” “modified,” or “new” and provided a confidence rating, when prompted.

Test Block

Participants saw 64 scenes during the Test Block (see Figure 2C). Sixteen scenes were the exact image seen during study (i.e., ‘repeated’ scenes), 16 scenes had undergone an item manipulation (i.e., ‘item’ scenes), 16 scenes had undergone a relational manipulation (i.e., ‘relational’ scenes), and 16 scenes were new (i.e., ‘novel’ scenes). Critically, a yoked design was used; three participants saw the exact same version of a scene during test, but differential

viewing histories among the three participants rendered the scene either manipulated, repeated, or novel (see Figure 3). This yoked design means that any differences in viewing, across conditions, could not be due to differences in features of the scenes presented during the test phase. Instead, any differences in viewing patterns would be directly attributable to differences in encoding history. Scenes were presented equally often as repeated, manipulated, or novel across participants.

Figure 3
Yoking Procedure at Test



Note. Representative example of a yoked scene during study and test for three different participants. Scenes during test were identical across participants but varied by encoding history.

Following central fixation, the experimenter initiated the trial, and a scene was presented for 6 s. After the scene disappeared from the screen, participants were prompted to respond via button press whether the scene was the “same” as one they had studied, had been “modified” somehow, or was “new.” Then, participants were asked to rate their recognition confidence on a scale from 1 (“just guessing”) to 3 (“absolutely certain”) with a button-press response. In each case, response options remained on the screen until a response was made. At the end of the experiment, participants were debriefed.

Data Processing and Analysis

Trials were flagged and removed from analyses when eye position was lost or unreliable. As in previously published work (e.g., Hannula, Ranganath, et al., 2010), bad trials were removed if the total viewing time was less than 65% of the trial duration. This resulted in the loss of 1.59% of trials ($SD = 4.32$) across autistic and non-autistic participants. To examine differences in processing of and attention toward critical items, orienting question accuracy and response times were calculated for button-press responses made during Study Block 2. Recognition accuracy and confidence ratings were calculated to determine whether explicit memory performance during the Test Block differed between groups.

To examine viewing effects, regions of interest (ROIs) were drawn for each scene corresponding to the location(s) of critical objects embedded in the scenes. For scenes assigned to the item condition (and yoked repeated/novel scenes), a single ROI corresponding to the location of the critical item (i.e., the item that replaced a different exemplar during the test phase in modified scenes and the same item in repeated/novel scenes) was defined. For scenes assigned to the relational condition (and their yoked counterparts), two ROIs were defined. One of the ROIs was occupied by the critical object (i.e., the filled region) and the other ROI corresponded to the location in which the object had been located during the study phase for modified scenes (i.e., the empty region). Reported analyses focused on viewing directed to these regions of interest.

To determine whether there were differences in viewing between groups during Study Blocks 1 and 2, the proportion of total viewing (in ms) directed to these regions was calculated. During the Test Block, consistent with past work (e.g., Hannula, Ranganath, et al., 2010), viewing effects between groups were compared using two calculated indices, referred to as

memory for repetition and *memory for detail*. The *memory for repetition* measure was used to determine whether there were differences in viewing due to memory for the scenes themselves, absent any modification. Comparisons were made between novel scenes (presented for the first time during test) and repeated scenes (presented during study and test). The *memory for detail* index was used to determine whether item-specific and/or relational changes affected viewing of critical objects. In this case, comparisons were made between repeated scenes (presented during study and test) and modified scenes (in which an item or relational change occurred at test). Since potentially subtle differences in retrieval-related eye movements were predicted, the repetition- and detail-based indices were calculated using four different dependent measures during the Test Block. These viewing measures included differences in total viewing time of the ROIs (i.e., proportion of total viewing time in ms), differences in the speed with which the ROIs were fixated (i.e., latency to the ROI from the onset of the trial in ms), and differences in first gaze viewing patterns to the ROIs (i.e., first gaze duration in ms, number of fixations in the first gaze).

Statistical Contrasts

Mauchly's test of sphericity was calculated for all reported mixed model ANOVAs with more than one degree of freedom in the numerator. If sphericity was violated, Greenhouse-Geisser adjusted degrees of freedom and p -values were reported along with the corresponding epsilons ($G-G \epsilon$). Levene's test for homogeneity of variances was calculated for all reported ANOVAs and t -tests. If the assumption of homogeneity of variances was violated, Welch's one-way ANOVAs were calculated. Two-tailed post-hoc statistical tests were Bonferroni corrected for multiple comparisons, and p -values were adjusted to reflect this correction. Partial eta-squared (η_p^2), Cohen's d , Hedge's g (to account for unequal sample sizes), and Glass's Δ (to

account for significant differences in sample standard deviations) were calculated as indices of effect size.

Pearson's correlations were calculated between eye-movement indices during study and subsequent memory performance and retrieval-related eye movements at test for both autistic and non-autistic participants to examine the relationship between study and test performances. To determine whether relevant demographic variables (e.g., age) or cognitive characteristics (e.g., scores on cognitive measures) could predict autistic and non-autistic participant's behavioral and eye-movement performances at test, multiple linear regressions were calculated.

Bayes factors were calculated in R (package BayesFactor) for ANOVAs and post-hoc *t*-tests that were non-significant during the Test Block to determine whether such results were likely to have been obtained under the null or alternative hypothesis, or whether results did not favor either hypothesis. For ANOVA results, a model with only main effects of Group (autistic, non-autistic), Scene Type (repeat, item, relational, novel), and ROI (for relational scene total viewing time contrasts only; filled, empty), and a model with the main effects as well as the interaction were compared to a model containing only the main effects of Scene Type and ROI (i.e., excluding the main effect of group). This allowed us to determine whether the data favored the models that included Group as a factor. For *t*-test results, a comparison was made between the alternative hypothesis (i.e., differences between groups) and the null hypothesis (i.e., no differences between groups). Conventionally, a Bayes factor greater than 3 provides substantial evidence for the alternative hypothesis and a Bayes factor less than 0.33 provides substantial evidence for the null hypothesis, while any value between 3 and 0.33 indicates weak or “anecdotal” evidence (Dienes, 2014).

Results

Behavioral Performance

Orienting Question Performance

Orienting question accuracy from Study Block 2 was compared for repeated, item, and relational scenes using Welch's ANOVAs with factor Group (autistic, non-autistic). The orienting question had the intended effect, with participants across groups responding correctly on 85% of all trials. Across scene types, differences between groups were not significant, Welch's F 's ≤ 1.95 , p 's $\geq .18$, Glass's Δ 's $\leq .68$.

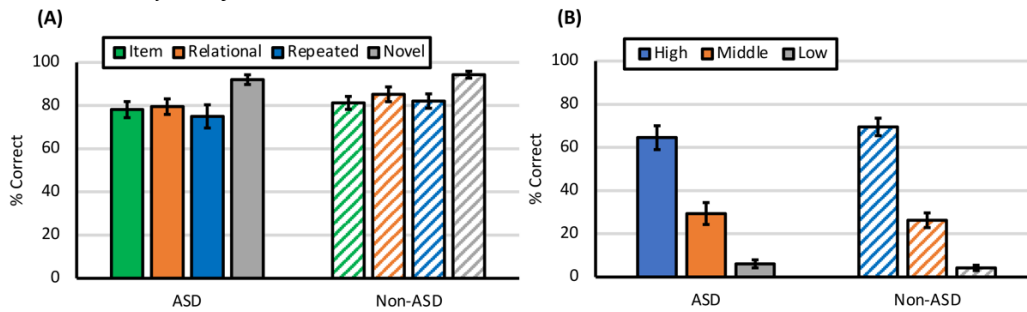
Orienting question response times from Study Block 2 were compared using mixed model ANOVAs with the factors Group (autistic, non-autistic) and Scene Type (repeated, item, relational). Across all participants, orienting question response times (in ms) to scene conditions were significantly different, $F(2, 76) = 30.03$, $p < .0001$, $\eta_p^2 = .44$. Post-hoc follow-up t -tests were also significant, t 's(39) ≥ 2.81 , p 's $\leq .024$, d 's $\geq .35$, with the quickest responses made for item scenes ($M = 3318.64$, $SD = 270.99$), followed by repeated scenes ($M = 3494.05$, $SD = 255.56$), and finally by relational scenes ($M = 3583.14$, $SD = 248.01$). This significant difference between scene types makes sense in the context of the orienting question; participants took the longest to respond to the orienting question when they were required to make judgments about spatial relationships between objects (i.e., for scenes that subsequently underwent a relational change) and were quickest to respond when they were required to make judgments about object features (i.e., for scenes that subsequently underwent an item change), with repeated scenes (half accompanied by an item-specific orienting question, half accompanied by a relational orienting question) falling in the middle. There was no significant main effect of Group or interaction between Group and Scene Type, F 's ≤ 2.22 , p 's $\geq .12$.

Recognition Performance

Recognition performance and confidence ratings from the Test Block were compared using mixed model ANOVAs with the factors Group (autistic, non-autistic) and Scene Type (repeated, item, relational, novel) for recognition performance and Group (autistic, non-autistic) and Confidence Level (high, middle, low) for confidence ratings (see Figure 4). Results of the recognition test administered at the end of the experiment confirmed that all scene types were successfully encoded. Recognition accuracy was well above chance level, $p < .0001$, across all participants (see Figure 4A). Across groups, participants identified the correct scene type (from three alternatives: same, modified, new) on 83% of trials ($SD = 10.08\%$). Recognition accuracy was significantly different between scene types for all participants, $F(2.42, 92.33) = 10.37, p < .0001, G-G \varepsilon = .81, \eta_p^2 = .21$, with significantly higher accuracy for novel scenes relative to relational, item, and repeated scenes, $t's(39) \geq 4.35, p's \leq .0006, d's \geq .84$. There was no significant effect of Group or interaction between Group and Scene Type, $F's \leq 2.09, p's \geq .16$.

When correct responses were separated by confidence ratings (see Figure 4B), there was a significant difference in accuracy for all participants, $F(1.15, 43.74) = 92.50, p < .0001, G-G \varepsilon = .58, \eta_p^2 = .71$, with greatest accuracy for high confidence responses, followed by middle confidence responses, and then low confidence responses, $t's(39) \geq 6.43, p's \leq .0003, \text{Glass's } \Delta's \geq 1.22$. Non-autistic participants reported marginally higher confidence ratings for their correct responses than autistic participants, $F(1, 38) = 3.62, p = .065, \eta_p^2 = .087$, but there was no significant interaction between Group and Confidence Level, $F(1.15, 43.74) = 0.45, p = .53$.

Figure 4
Recognition Memory Performance



Note. (A) Recognition accuracy for item, relational, repeated, and novel scenes by group. (B) Recognition accuracy subdivided by confidence responses and group.

Viewing Behavior

Study Blocks

Proportion of Viewing Time. Proportion of viewing time of ROIs was compared using mixed model ANOVAs with the factors Group (autistic, non-autistic) and Scene Type (repeated, item) for scenes assigned to the item condition and with the factors Group (autistic, non-autistic), Scene Type (repeated, relational), and ROI (filled, empty) for scenes assigned to the relational condition.

Study Block 1. Across both groups, there was a marginally significant tendency for participants to spend more time viewing the critical region of repeated scenes relative to item scenes, $F(1, 38) = 4.06, p = .051, \eta_p^2 = .096$. Group differences and the interaction between Scene Type and Group were not significant in the item condition, F 's(1, 38) $\leq 0.82, p$'s $\geq .37$.

As expected, all participants spent a disproportionate amount of time viewing the ROI containing the critical item as compared to the empty ROI (which was not meaningful during study) in relational scenes and their yoked, repeated counterparts, $F(1, 38) = 384.41, p < .001, \eta_p^2 = .91$. There were no significant viewing differences to the critical ROIs between Groups or Scene Types, or a Group x Scene Type interaction, F 's(1, 38) $\leq 0.60, p$'s $\geq .38$.

Study Block 2. There were no significant effects of Scene Type or Group, or a Scene Type by Group interaction for item scenes and their repeated counterparts, $F's(1, 38) \leq 0.35, p's \geq .56$.

The presence of orienting questions during Study Block 2, which directed participants' attention to the critical, filled region of each scene, resulted in disproportionate viewing of this region as compared to the empty region of relational scenes and their yoked, repeated counterparts for all participants, $F(1, 38) = 663.49, p < .001, \eta_p^2 = .95$. This disproportionate viewing of the filled region was the driving force behind a significant ROI x Scene Type x Group interaction as well, $F(1, 38) = 4.26, p = .046, \eta_p^2 = .10$. There were no significant viewing differences to the critical ROIs between Groups or Scene Types and no additional interactions, $F's(1, 38) \leq 2.28, p's \geq .14$.

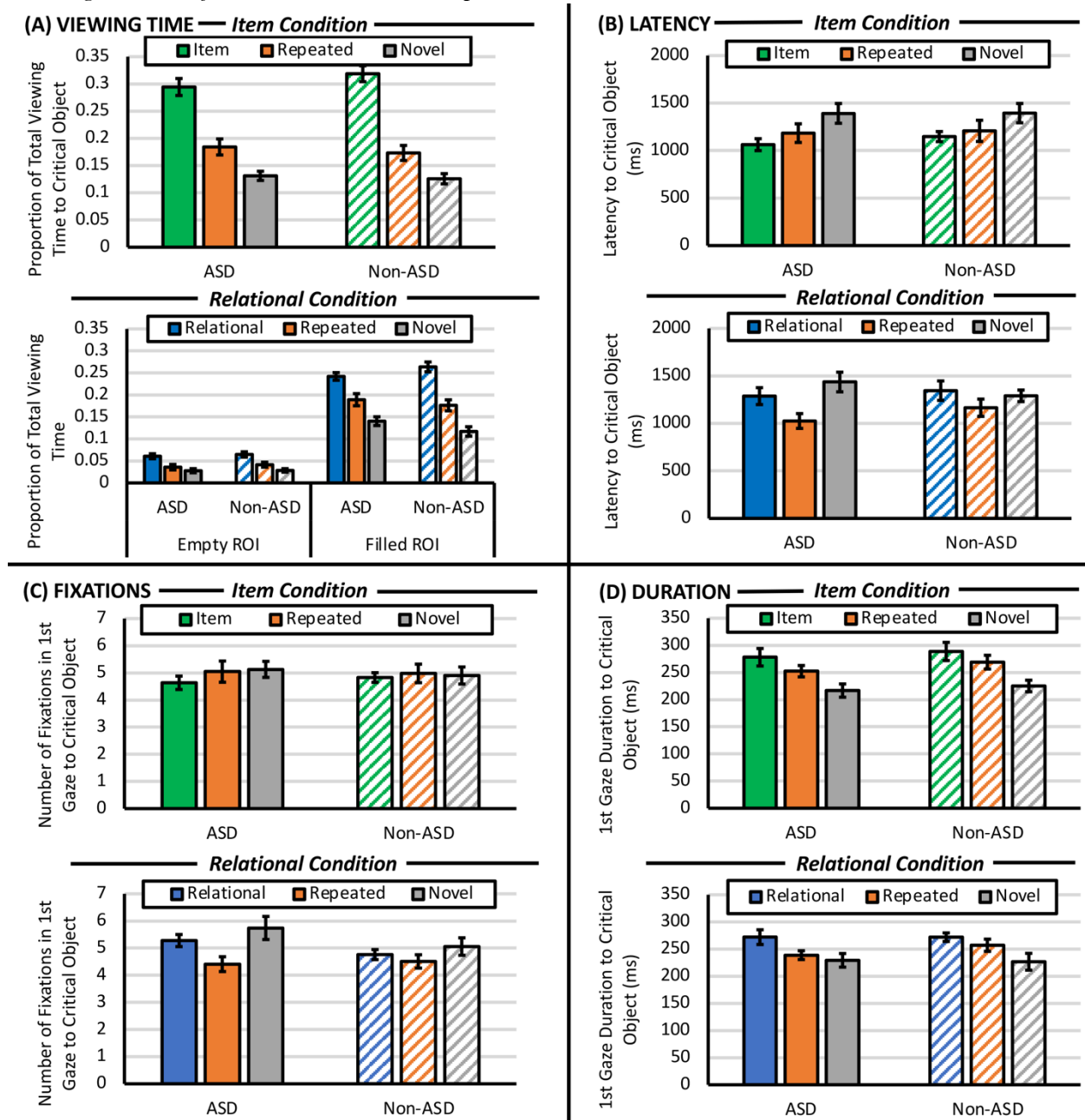
Test Block

All four eye movement measures (i.e., proportion of viewing time, latency to ROI, number of fixations, first gaze duration), prior to difference score calculations, are presented for each of the four scene types (i.e., item, relational, repeated, novel) in Figure 5.

Memory for Repetition. To determine whether critical ROIs in repeated scenes were prioritized over critical ROIs in their yoked, novel counterparts, the *memory for repetition* measure was defined as a difference score based on viewing to repeated scenes minus novel scenes. Difference scores based on proportion of viewing time were compared using one-way ANOVAs with the factor Group (autistic, non-autistic) for scenes assigned to the item condition and mixed model ANOVAs with the factors Group (autistic, non-autistic) and ROI (filled, empty) for scenes assigned to the relational condition. All other repetition-based dependent

measures (i.e., latency to ROI from trial onset, number of fixations in first gaze, first gaze duration) were compared using mixed model ANOVAs with the factor Group (autistic,

Figure 5
Viewing Patterns for Item, Relational, Repeated, and Novel Scenes



Note. (A) Proportion of total viewing time (in ms). (B) Latency to ROI from trial onset (in ms). (C) Number of fixations in first gaze. (D) First gaze duration (in ms).

non-autistic) and Condition (item, relational). There were an insufficient number of trials with fixations to the empty ROI to include an ROI factor; thus, the Condition factor (restricted to just the filled ROI) included all four scene types (item/relational, repeated, novel) split into their respective item and relational conditions.

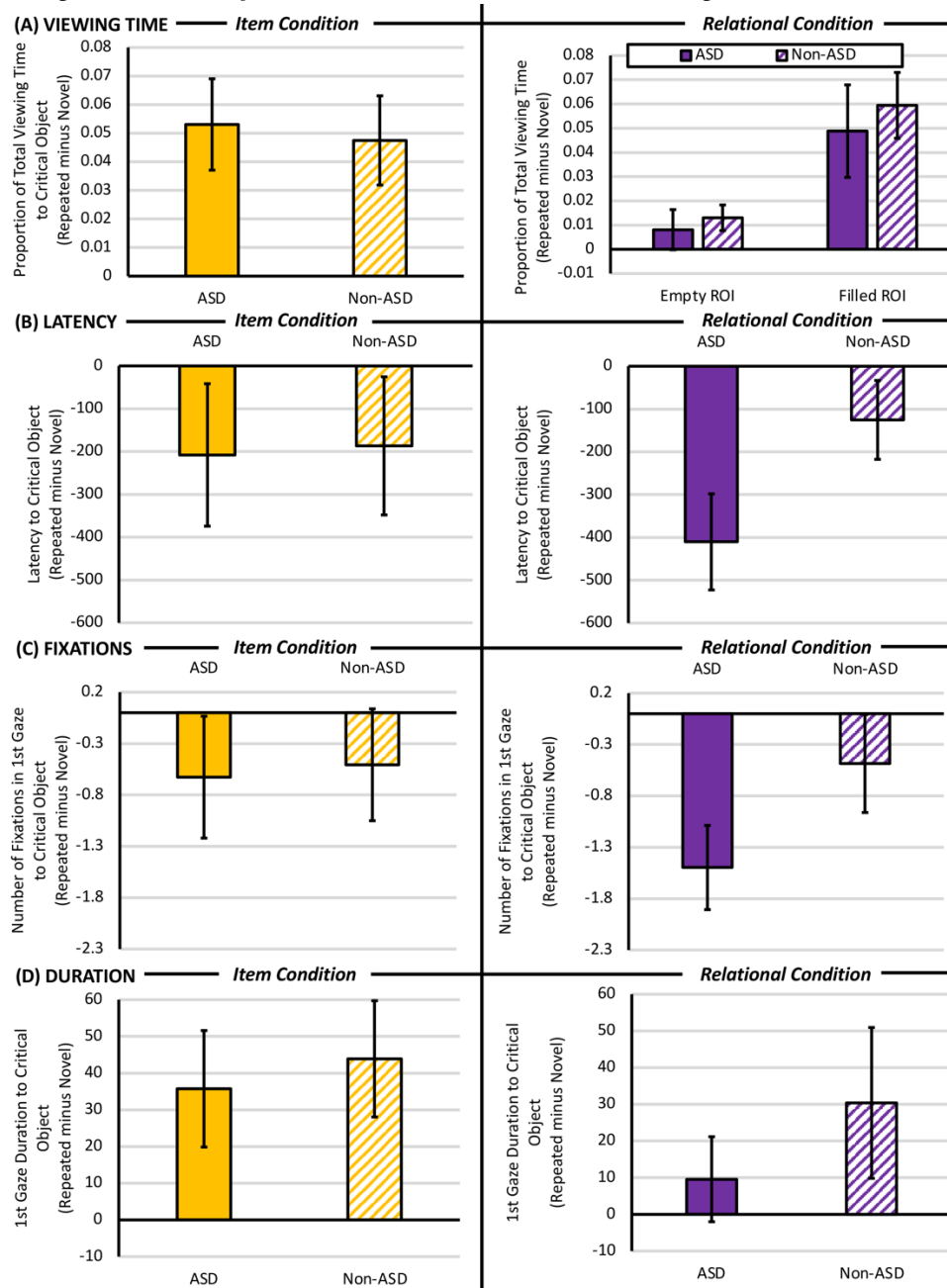
Proportion of Viewing Time. Differences scores based on proportion of total viewing time (in ms) directed to the critical regions were calculated (see Figure 6A). There was no significant effect of Group in the proportion of viewing difference scores (i.e., repeated minus novel) for scenes assigned to the item condition, $F(1, 38) = .062, p = .81$.

As expected, all proportional viewing difference scores were greater for the ROI containing the critical item as compared to the empty ROI for scenes assigned to the relational condition for all participants, $F(1, 38) = 11.85, p = .001, \eta_p^2 = .24$. There were no significant main effect of Group or Group x ROI interaction, F 's(1, 38) $\leq .38, p$'s $\geq .54$.

Latency to ROI From Trial Onset. Difference scores based on the latency from onset of the trial to the first fixation on the critical ROI (in ms) were calculated (see Figure 6B). There were no significant main effects of Group or Condition in latency to ROI difference scores and no Group x Condition interaction, F 's(1, 38) $\leq 1.47, p$'s $\geq .23$.

Number of Fixations in First Gaze. Difference scores based on the number of fixations within the first gaze to the critical region were calculated (see Figure 6C). There was a marginally significant main effect of Condition, $F(1, 38) = 3.30, p = .077$, with higher fixation difference scores for scenes in the relational condition relative to the item condition for all participants (although there had been no modifications to the critical regions). This marginal difference between scenes assigned to the item and relational conditions may have been an artifact of the orienting question during Study Block 2 – participants may have made more

Figure 6
Memory for Repetition Index for Autistic and Non-Autistic Participants



Note. ‘Memory for repetition’ = viewing to repeated scenes – viewing to yoked, novel scenes for item and relational conditions. (A) Proportion of total viewing time (in ms). (B) Latency to ROI from trial onset (in ms). (C) Number of fixations in first gaze. (D) First gaze duration (in ms).

fixations in their first gaze toward the critical region during test because they were revisiting the same spatial relationships among objects that they were asked to consider in the relational scenes

during study. There was no significant effect of Group or Group x Condition interaction, $F's(1, 38) \leq 1.14, p's \geq .29$.

First Gaze Duration. Difference scores based on the duration of the first gaze toward the critical ROI (in ms) were calculated (see Figure 6D). There were no significant main effects of Group or Condition and no Group x Condition interaction, $F's \leq .78, p's \geq .39$.

Memory for Detail. To determine whether critical ROIs in modified item or relational scenes were prioritized relative to critical ROIs in repeated scenes, the *memory for detail* measure was operationalized as a difference score based on viewing to item or relational scenes minus their yoked, repeated counterparts. Difference scores based on proportion of viewing time were compared using one-way ANOVAs with the factor Group (autistic, non-autistic) for scenes assigned to the item condition and mixed model ANOVAs with the factors Group (autistic, non-autistic) and ROI (filled, empty) for scenes assigned to the relational condition. All other detail-based dependent measures (i.e., latency to ROI from trial onset, number of fixations in first gaze, first gaze duration) were compared using mixed model ANOVAs with the factor Group (autistic, non-autistic) and Condition (item, relational). Again, there were an insufficient number of trials with fixations to the empty ROI to include an ROI factor, so the Condition factor (restricted to just the filled ROI) included all four scene types (item/relational, repeated, novel) separated into their respective item and relational conditions.

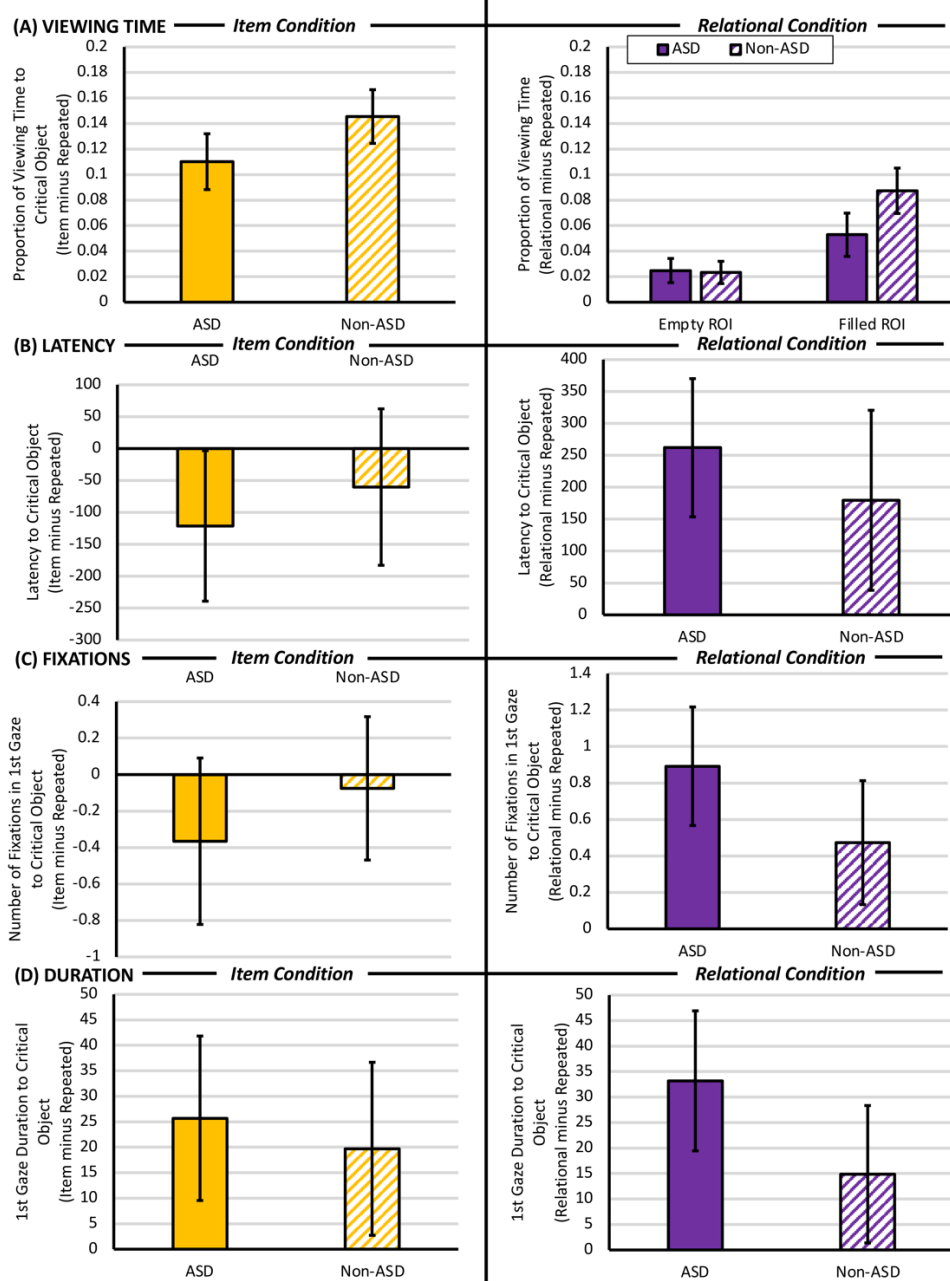
Proportion of Viewing Time. Difference scores based on proportion of total viewing time (in ms) directed to the critical regions were calculated (see Figure 7A). Across groups, there was no significant Group effect in proportion of viewing differences scores (i.e., item minus repeated) for item/yoked scenes, $F(1, 38) = 1.34, p = .26$.

Mirroring the *memory for repetition* metric, all proportional viewing difference scores were greater for the ROI containing the critical item relative to the empty ROI for relational/yoked scenes for all participants, $F(1, 38) = 11.83, p = .001, \eta_p^2 = .24$. Once again, there were no significant effects of Group or Group x ROI interaction, F 's(1, 38) $\leq .1.80, p$'s $\geq .19$.

Latency to ROI From Trial Onset. Difference scores based on latency from onset of the trial to the first fixation on the critical ROI (in ms) were calculated (see Figure 7B). There was a significant main effect of Condition, $F(1, 38) = 6.10, p = .018, \eta_p^2 = .14$, due to greater latency difference scores for scenes in the relational condition as compared to scenes in the item condition for all participants. Specifically, it took participants longer to fixate the filled region in scenes that underwent a relational change relative to their repeated counterparts, likely due to the change in spatial relationships among objects, whereas participants were quicker to fixate the filled region in scenes that underwent an exemplar change as compared to their repeated counterparts. There was no significant main effect of Group or Group x Condition interaction, F 's(1, 38) $\leq .32, p$'s $\geq .57$.

Number of Fixations in First Gaze. Difference scores based on the number of fixations within the first gaze to the critical ROI were calculated (see Figure 7C). Similar to the latency effect above, there was again a significant main effect of Condition, $F(1, 38) = 7.82, p = .008$, with higher fixation difference scores for scenes in the relational condition relative to the item condition across all participants (i.e., more fixations made toward filled regions of relational scenes relative to yoked counterparts versus fixation difference scores for scenes assigned to the item condition). There was no significant effect of Group or Group x Condition interaction, F 's(1, 38) $\leq 2.12, p$'s $\geq .15$.

Figure 7
Memory for Detail Index for Autistic and Non-Autistic Participants



Note. ‘Memory for detail’ = viewing to modified (i.e., item or relational) scenes – viewing to yoked, repeated scenes for item and relational conditions. (A) Proportion of total viewing time (in ms). (B) Latency to ROI from trial onset (in ms). (C) Number of fixations in first gaze. (D) First gaze duration (in ms).

First Gaze Duration. Difference scores based on the duration of the first gaze toward the critical ROI (in ms) were calculated (see Figure 7D). There were no significant main effects of Group or Condition or a Group x Condition interaction, F 's(1, 38) $\leq .52$, p 's $\geq .48$.

Correlation Analyses

To determine whether encoding- and retrieval-related performances were associated, correlations between encoding-related eye movements (i.e., proportion of viewing time to filled ROIs only), subsequent memory performance (i.e., recognition accuracy, collapsed across confidence levels and scene types), and retrieval-related eye movements (i.e., proportion of viewing time difference scores) were calculated for autistic and non-autistic participants separately.

For non-autistic participants, more time spent viewing the filled critical regions of subsequently repeated item and relational scenes during Study Block 2 was marginally correlated with greater recognition accuracy, r 's $\geq .42$, p 's $\leq .053$. In other words, increased viewing of critical regions during study was associated with better recognition performance. No additional correlations between encoding and retrieval measures were significant for non-autistic participants, p 's $\geq .11$.

For autistic individuals, more time spent viewing the filled critical region of subsequently modified relational scenes during Study Block 1 was correlated with greater viewing of the filled ROI (where the critical object moved) in relational scenes during the Test Block, $r = .50$, $p = .033$. Similarly, during Study Block 2, greater viewing of the critical ROI in subsequently modified item scenes was associated with more time spent viewing the filled ROI (containing a new item exemplar) in item scenes during the Test Block, $r = .56$, $p = .015$. No further correlations were significant for autistic participants, p 's $\geq .13$.

Regression Analyses

Test Block

Multiple linear regression analyses were calculated to determine whether relevant demographic variables (age) or cognitive characteristics (WASI-II index scores: VCI, PRI; NIH Toolbox® Cognition Battery subtest scores: FICA, DCCS, PSM, LSWM) predicted autistic and non-autistic participant's behavioral and eye-movement performances at test (i.e., recognition accuracy, collapsed across confidence levels and scene types; memory for repetition and memory for detail difference scores). For autistic participants, ADOS SA and RRB severity scores were also included as predictors in regression analyses.

Recognition Performance. There were no significant predictors for recognition accuracy for non-autistic or autistic participants, p 's $\geq .075$.

Proportion of Viewing Time. Demographic and cognitive characteristics did not significantly predict proportion of viewing time to the critical regions for non-autistic or autistic groups at test, p 's $\geq .21$.

Latency to ROI From Trial Onset. Demographic and cognitive characteristics did not significantly predict latency to ROI from trial onset for non-autistic participants, p 's $\geq .21$.

For autistic individuals, demographic/cognitive variables contributed to 88.6% of the variance in latency to the filled ROI in repeated scenes assigned to the *item* condition, adjusted $R^2 = .54$, $F(9, 8) = 3.24$, $p = .056$. Age ($\beta = -.63$, $p = .029$), ADOS Social Affect (SA) severity scores ($\beta = -.58$, $p = .028$), and Picture Sequence Memory (PSM) test scores ($\beta = -.68$, $p = .009$) significantly predicted latency to ROI. Specifically, increasing age, increasing social affective impairment, and higher performances on an episodic memory task were predictive of decreased

(i.e., quicker) latencies. There were no additional variables that predicted latency to ROI for autistic individuals, p 's $\geq .17$.

Number of Fixations in First Gaze. None of the demographic or cognitive characteristics significantly predicted number of fixations in the first gaze for non-autistic individuals, p 's $\geq .17$.

For autistic participants, demographic/cognitive variables accounted for 93.6% of the variance in number of fixations within the first gaze to the filled ROI of repeated scenes assigned to the *item* condition at test, adjusted $R^2 = .74$, $F(9, 8) = 6.23$, $p = .008$. Increasing age ($\beta = -.62$, $p = .008$), higher ADOS Social Affect (SA) severity scores ($\beta = -.67$, $p = .003$), greater Picture Sequence Memory (PSM) test scores ($\beta = -.66$, $p = .002$), greater Verbal Comprehension Index (VCI) scores ($\beta = -.65$, $p = .016$), and decreasing Perceptual Reasoning Index (PRI) scores ($\beta = .51$, $p = .014$) significantly predicted fewer fixations in the first gaze to the critical ROI in repeated item scenes. Additionally, several demographic/cognitive variables predicted 88.9% of the variance in number of fixations within the first gaze to the filled ROI of repeated scenes assigned to the *relational* condition at test, adjusted $R^2 = .56$, $F(9, 8) = 3.36$, $p = .051$. Specifically, decreasing test scores on the Perceptual Reasoning Index (PRI; $\beta = -3.57$, $p = .007$), Dimensional Change Card Sort test (DCCS; $\beta = -3.29$, $p = .013$), and List Sorting Working Memory (LSWM) test ($\beta = -.86$, $p = .014$) and increasing test scores on the Picture Sequence Memory (PSM) test ($\beta = 2.60$, $p = .031$) significantly predicted an increased number of fixations in the first gaze to the critical ROI for repeated relational scenes. No additional variables significantly predicted number of fixations for autistic participants, p 's $\geq .095$.

First Gaze Duration. Demographic/cognitive factors did not predict first gaze duration for non-autistic individuals, p 's $\geq .23$.

For autistic participants, the demographic and cognitive predictors explained 92.6% of the variance in gaze duration to the filled ROI of repeated scenes in the *relational* condition at test, adjusted $R^2 = .70$, $F(9, 8) = 5.32$, $p = .014$. Age ($\beta = .57$, $p = .019$), ADOS Restricted, Repetitive Behavior severity scores ($\beta = .43$, $p = .053$), Flanker Inhibitory Control and Attention (FICA) test scores ($\beta = .60$, $p = .047$), Picture Sequence Memory (PSM) scores ($\beta = .40$, $p = .038$), Dimensional Change Card Sort (DCCS) test scores ($\beta = -1.17$, $p = <.001$), and List Sorting Working Memory (LSWM) test scores ($\beta = -.81$, $p = .007$) significantly predicted gaze duration to the critical region. In other words, longer gaze durations during the initial fixation on the critical regions of repeated relational scenes were predicted by increasing age, greater severity of restricted and repetitive behaviors, greater inhibitory control, higher performances on an episodic memory task and decreasing cognitive flexibility and working memory abilities. No additional variables significantly predicted gaze duration for autistic participants, p 's $\geq .36$.

Bayes Factor Analyses

To determine whether non-significant results during the Test Block were likely to have been obtained under the null or alternative hypothesis, Bayes factors were calculated. Bayes factor analyses most often came down in favor of the null hypothesis, though several were determined as “inconclusive,” including the *memory for detail* measure (modified scenes – repeated scenes; $BF = .42$), as well as recognition accuracy for repeated scenes ($BF = .86$) and relational scenes ($BF = .41$). None of the analyses were consistent with the models that included Group as a factor.

Discussion

The current study examined whether memory-specific viewing patterns toward realistic, non-social scenes differed between autistic and non-autistic individuals. Critically, we employed

an eye tracking paradigm that equated task difficulty across item-specific and relational conditions (i.e., Cooper et al., 2015; Hannula, Ranganath, et al., 2010) to control for differential complexity of tasks that may have contributed to past findings, in addition to utilizing both direct (i.e., explicit responses) and indirect (i.e., eye movements) measures of memory. Orienting question accuracy and response times were not significantly different between autistic and non-autistic participants during Study Block 2, suggesting that both groups attended to relevant regions of scenes. Further, both groups showed standard viewing effects during Study Blocks 1 and 2, with greater prioritization of filled critical regions relative to empty ROIs. There was no evidence for differential viewing of critical regions across groups during Study Blocks, suggesting that encoding quality of scenes was relatively equitable between autistic and non-autistic individuals.

With respect to memory performance, no differences emerged in recognition accuracy between groups, though autistic participants demonstrated a tendency to be less confident in their correct responses. Both groups exhibited standard repetition-based viewing effects during the Test Block, with increased viewing time and quicker latencies to critical regions of scenes that were repeated during test. Memory-based viewing patterns were also intact across groups, with a disproportionate amount of time spent viewing modified regions in relational scenes. Additionally, all participants were slower to fixate on and made more fixations to the critical, filled region of scenes that underwent a relational change as compared to scenes that underwent an item change. Taken together, and in line with the results of the Study Blocks, there were no significant differences in direct or indirect memory-based measures between autistic and non-autistic participants. Furthermore, the preponderance of Bayes factors analyses suggested that

non-significant results more strongly favored the null hypothesis relative to the alternative hypothesis (i.e., which predicted the presence of group differences).

Supplemental analyses revealed that non-autistic participant's viewing behavior during study was correlated with subsequent recognition memory accuracy. In contrast, autistic participant's viewing patterns during study were associated with viewing during test but *not* subsequent recognition performance. Interestingly, non-autistic participant's memory performances and viewing effects during test were not predicted by demographic or cognitive characteristics of the sample. However, repetition-based latency, fixation quantity, and gaze duration eye-movement measures were predicted by age, autism symptom severity, verbal and non-verbal IQ indices, and performances on episodic memory, executive functioning, and working memory tasks in autistic individuals. In sum, though direct and indirect memory measures were, at the surface level, equivalent across groups, auxiliary analyses suggest more subtle group differences in the relationship between study and test performances as well as the effect of sample characteristics on test performances.

As outlined above, past work has demonstrated that episodic memory processes may be atypical in autistic individuals. However, the type of representational content impacted by episodic memory impairments has been contested among prior studies, with some authors documenting deficits restricted to item-specific memory (Cooper, Plaisted-Grant, et al., 2017; Solomon et al., 2016), selective relational memory deficits (Bigham et al., 2010; Bowler et al., 2014; Cooper, Richter, et al., 2017; Desaunay, Clochon, et al., 2020; Lind & Bowler, 2009), impairments in both item and relational memory (Massand & Bowler, 2015; Mogensen et al., 2020; Ring et al., 2016; Semino et al., 2018), or no item-specific or relational memory deficits (Hogeveen et al., 2020; Lind et al., 2014; Ring et al., 2015, 2017; Souchay et al., 2013). One

proposed explanation for contradictory findings has been the differential complexity of past item-specific and relational memory tasks (see Cooper & Simons, 2019 for review), an issue that Cooper and colleagues (2015) attempted to address by utilizing a similar behavioral task to the one used in the current study, which matched demands across item and relational tasks. Results of their work showed that autistic individuals correctly identified fewer item and relational changes than their non-autistic peers, a finding taken as evidence for a potential deficit in both item-specific and relational memory in autism (Cooper et al., 2015).

Given the task similarities between the current work and Cooper et al.'s (2015) study, one may question why we did not document an item-specific or relational impairment in behavioral memory performances in the present study. It is possible that the addition of the second study phase, which provided participants with a directed viewing task (i.e., in the form of orienting questions), successfully mitigated attentional or processing deficits that may have otherwise impacted explicit recognition memory performance in the autistic group in the current study. This hypothesis is consistent with past work that has demonstrated recovered memory performances following explicit encoding manipulations (Bowler et al., 2010; Cooper, Plaisted-Grant, et al., 2017; Gaigg et al., 2008) or implicit recognition tasks (Ring et al., 2017), as well as poorer memory performance with incidental encoding tasks (e.g., Solomon et al., 2016). Not only did the use of a second study phase allow for greater control of attentional processes during encoding, but the use of indirect (i.e., eye-movement based) attention and memory measures also eliminated the need for a complicated behavioral memory task, which often requires other cognitive functions that may be compromised in autistic participants (e.g., abstraction; e.g., Solomon et al., 2011). Indeed, equivalent group performances in orienting question accuracy and response times during Study Block 2, as well as equitable recognition memory performances

during the Test Block, suggest that the current task demands were not disproportionately taxing for autistic participants. Though there were no quantitative differences in recognition accuracy across groups, we did observe a marginal tendency for autistic participants to report less confidence in their mnemonically accurate responses, which aligns with past work documenting attenuated memory confidence in autism (Cooper et al., 2016; Grainger et al., 2014; Wojcik et al., 2013).

A strength of the current paradigm was the decision to record eye movements across both encoding and retrieval phases, which provided the opportunity to examine at which point in the memory process group differences may emerge. Of the few previous eye-tracking studies that recorded encoding-related viewing behaviors, none reported differences in encoding-related eye movements between autistic and non-autistic groups (Cooper, Plaisted-Grant, et al., 2017; Loth et al., 2011), a finding that was replicated here and extended to include viewing behavior in the context of a well-matched item-specific and relational memory task. In contrast, atypical retrieval-related eye movements have been documented for autistic participants in scene recognition and relational memory tasks (Cooper, Plaisted-Grant, et al., 2017; Ring et al., 2017). Specifically, in a relational memory task, it was reported that autistic participants spent less time viewing relevant regions of scenes as compared to their non-autistic counterparts (Ring et al., 2017). Several factors may account for discrepant findings between this prior study and the current one, including retrieval task demands and design features. In Ring and colleagues (2017) work, participants were required to switch between tasks during retrieval, either placing the presented object in the location where it was studied in the scene (on *direct* trials) or in a new location (on *indirect* trials). This task likely placed a greater burden on additional cognitive abilities, such as cognitive flexibility (i.e., set shifting), a domain which has been identified as a

weakness in autism (e.g., Andreou et al., 2022; Van Eylen et al., 2011). Further, constraints of the experimental design, such as critical analyses based on very few trials (24 total trials), raise concern for the possibility of Type I errors. Regardless, however, it is important to not discount the possible impact of the present study's controlled encoding task, accompanied by a relatively simple retrieval task, on the absence of group differences across Study and Test Blocks.

More generally, the absence of differences in eye-movement-based memory effects should not be taken as evidence for equivalent memory processes in autistic and non-autistic individuals. For example, despite explicit memory performances in autistic participants that often appear to mirror recognition memory performances in non-autistic individuals, electrophysiological studies have reported differences in magnitude and/or spatial location of event-related potentials (ERPs) associated with memory retrieval (Desaunay, Clochon, et al., 2020; Massand & Bowler, 2015; Massand et al., 2013) and imaging studies have documented hyper-recruitment and connectivity differences between autistic and non-autistic individuals (Hogeveen et al., 2020), indicating that compensatory neural processes may contribute to seemingly intact behavioral memory performances. Indeed, results of correlation and regression analyses in the present study were suggestive of a similar possibility. Consistent with prior findings (e.g., Cooper, Plaisted-Grant, et al., 2017), increased viewing of critical regions during Study Block 2 was correlated with greater recognition accuracy for non-autistic participants only. Unexpectedly, however, there was an association between viewing patterns during Study Blocks 1 and 2 and the Test Block for autistic participants only, such that more time spent viewing critical regions of item and relational scenes during the Study Blocks was correlated with greater proportion of viewing of these subsequently modified regions during the Test Block. This dissociative pattern of correlations, together with the bias toward lower confidence in

memory judgments, suggests the presence of subtle differences in the quality of memory representations (e.g., subjective quality) and/or in the relationships between subcomponents of memory in ASD. Interestingly, the influence of specific demographic and cognitive characteristics on retrieval-related eye movements was only significant for autistic participants. Increasing age significantly predicted latencies, gaze durations, and number of fixations to critical regions during test, a finding which aligns with prior work that has documented age-related effects on recognition memory performance for autistic (vs. non-autistic) participants (e.g., Solomon et al., 2016). Future studies should carefully examine the relative impact of sample characteristics on memory performances, with a particular emphasis on cognitive domains that may be implicated in aberrant connectivity between the hippocampus and fronto-parietal networks (Cooper, Richter, et al., 2017; Gaigg et al., 2015).

Several limitations of the current study should be considered. First, specific characteristics of the sample included here may have contributed to the absence of group differences. For example, the autistic individuals who participated in this study did not have comorbid intellectual disability diagnoses ($IQ \geq 70$); thus, results may not be generalizable to all autistic individuals. Additionally, the age range of participants, spanning from adolescence to young adulthood in both autistic and non-autistic groups, may have obscured possible episodic memory differences between groups. Cognitive changes occur across development in autistic individuals (Lever & Geurts, 2016), and, more specifically, the neural circuits associated with memory continue to develop throughout the aging process (DeMaster & Ghetti, 2013; DeMaster et al., 2014; Grady et al., 2003; Naveh-Benjamin, 2000). Therefore, it is possible that memory deficits may only emerge later in adulthood in autism, when development of these networks are more fully matured. With these caveats in mind, the current study contributes to the growing

body of evidence that item-specific and relational memory measures may not be disproportionately impaired in autism, especially when structured encoding conditions are provided and when the complexity of memory tasks are equated. Instead, episodic memory differences between autistic and non-autistic individuals may be more subtle, and direct and indirect memory indices may be useful in fully characterizing these nuanced memory effects.

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