# Children with ASD Show Impaired Item-Space Recollection, But Preserved Item-Color Recollection

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Although individuals with autism spectrum disorder (ASD) have been often shown to display similar memory performance on semantic memory tasks compared to typically developing (TD) children, there is ongoing debate about whether and how their ability to remember specific past events (i.e., episodic memory) is impaired. We assessed a sample of 62 children with ASD and 72 TD children, ranging in age between 8 and 12 years on 2 memory tasks. Participants encoded a series of images and their association with either where they appeared on the screen (item-space association task) or with the color of an image's border (item-color association task). Children with ASD showed worse memory in the item-space association task compared to their TD peers, but comparable memory for the item-color association task. These differences persisted when age, intellectual quotient, and general item recognition memory were accounted for statistically. We interpret these results in light of evidence for specific deficits along the dorsal stream affecting processing of spatiotemporal information in ASD. ***Autism Res*** *2020, 13: 1985–1997.* © 2020 International Society for Autism Research and Wiley Periodicals LLC

**Lay Summary:** Episodic memory requires the ability to bind contextual details (such as color, location, etc.) to an item or event in order to remember the past with specific detail. Here, we compared children with autism spectrum disorder (ASD) and typically developing (TD) children on tasks examining episodic memory. Children with ASD recalled more poorly previously seen items and their associated space-related details, but they performed comparably to TD children on color details. We discuss the possible mechanisms that contribute to worse spatial processing/recall in ASD.

**Keywords:** ASD; episodic memory; middle childhood; signal detection theory; global processing

## Introduction

Episodic memory refers to the ability to remember events and their specific spatial or temporal context, as well as their other unique details (e.g., perceptual features, emotions involved at the time of the event) [Tulving, 1972; Tulving, 2002]. The ability to form episodic memories requires mechanisms that encode the association between the various features of an event (e.g., unique spatiotemporal features and interitem associations) [Diana, Yonelinas, & Ranganath, 2007; Eichenbaum & Cohen, 2001] and provides the foundation for the creation of autobiographical memories that are critical for the development of one's sense of self across time [Buckner & Carroll, 2007].

Given its importance, a number of studies examining memory in autism spectrum disorder (ASD) have focused on deficits in the processes that might support the ability to form coherent autobiographical memories [Adler, Nadler, Eviatar, & Shamay-Tsoory, 2010; Crane, Pring, Jukes, & Goddard, 2012; Goddard, Dritschel, Robinson, & Howlin, 2014]. However, other literature has focused instead on whether the relational processes responsible for integrating the spatiotemporal aspects of an experience may be affected [e.g., Bowler, Gaigg, & Gardiner, 2014; Ring, Gaigg, Altgassen, Barr, & Bowler, 2018]. Importantly, both of these relational mechanisms have been linked to the integrity of the hippocampus, because of its role in encoding and reinstating associative relations among event features [Konkel, Warren, Duff, Tranel, & Cohen, 2008; Konkel & Cohen, 2009].

Both atypical hippocampal structure and function have been found in ASD [DeLong, 1992; Reinhardt et al., 2019; Salmond et al., 2005]. Despite significant heterogeneity in ASD symptomatology, these previous findings motivate the hypothesis that individuals with ASD may exhibit specific differences compared to typically developing (TD) individuals in the relational binding processes that depend on hippocampal integrity and support rich and detailed episodic memories [Ben Shalom, 2003; Bowler, Gardiner, & Grice, 2000]. However, not all details

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may be affected similarly by the disorder, with memory for details supported by the dorsal stream more likely to be affected in ASD [Atkinson et al., 2006; Lajiness-O'Neill et al., 2005]. Previous findings have suggested altered processing of spatial and temporal information and preserved processing of object-specific features in ASD in perceptual and attentional tasks [Boucher, Mayes, & Bigham, 2012; Bowler, Gaigg, & Lind, 2011; Souchay, Wojcik, Williams, Crathern, & Clarke, 2013], raising the question of whether this tendency may extend to a differential ability to retain different types of details. Thus, the present study was conducted to test the hypothesis that children with ASD would be predominantly affected in their ability to remember spatial attributes of studied objects compared to color attributes of studied objects. We assessed memory performance with tasks that are matched on the level of retrieval demands, allowing us to minimize the possibility that factors generally associated with retrieval abilities [Bowler, Gardiner, & Berthollier, 2004; Gaigg, Gardiner, & Bowler, 2008] may account for our results.

*Episodic Memory Deficits in ASD*

Individuals with ASD have been shown to perform more poorly than neurotypical individuals in memory tasks [Boucher & Anns, 2018]. Those with ASD and intellectual functioning in the average or above average range are considered to have a mild declarative episodic memory impairment while semantic memory appears to be intact [Ben Shalom, 2003; Bowler, Gaigg, & Lind, 2011; Bowler et al., 2000]. Specifically, memory for autobiographical or person-related information [for review, see Lind, 2010] and contextual details [Semino, Ring, Bowler, & Gaigg, 2018] are more likely to be impaired.

However, autobiographical memory deficits and memory for social-related stimuli in ASD have been consistently hypothesized to result primarily from impaired sense of self or theory of mind [Adler et al., 2010; Lind, 2010], it has also been suggested that other nonsocial, nonautobiographical deficits in episodic memory are the result of difficulties in encoding and integrating complex relational (i.e., relating contextual details) information in ASD [Ben Shalom, 2009; Williams, Goldstein, & Minshew, 2006]. This hypothesis motivates the prediction that item recognition memory may be relatively preserved in ASD, whereas the capacity to recollect associative information may be impaired [Bowler et al., 2000]. Consistent with this prediction of a selective recollection deficit, Bigham, Boucher, Mayes, and Anns [2010] assessed memory using tasks that captured both the process of recollection (which requires processing of relational information) and familiarity (which reflects global memory strength) [Yonelinas, 2001]. They found that the deficits in individuals with ASD with higher than average cognitive ability were restricted to the recollection task, whereas the deficits in individuals with ASD and lower cognitive ability were present in both recollection and familiarity. However, Boucher et al. [2012] reported that individuals with moderately low cognitive ability and ASD exhibit impaired recognition memory compared to individuals with high cognitive ability and ASD, bolstering the notion that the observed deficits may extend beyond the associative component of episodic memory when the disorder is more severe. Overall, the heterogeneity of the disorder and differences in experimental design make it difficult to form a consensus about the nature of memory impairments in ASD.

Some accounts of episodic memory in ASD assert that encoding and storage processes are relatively unimpaired and that retrieval processes are responsible for difficulties with episodic memory. For example, based on the *Task Support Hypothesis* [Bowler et al., 2004], individuals with ASD perform comparably to TD when sufficient retrieval support is provided. In a study regarding eye-witness memory, children with ASD performed poorly compared to TD when they were asked to engage in free recall, but performed comparably when their retrieval processes were guided by more specific questions [McCrory, Henry, & Happé, 2007]. The effects of retrieval support are interpreted as lessening the demands on other cognitive processes such as executive function, which may be necessary in free recall and impaired in ASD [Craig et al., 2016].

Another relevant dimension to understand episodic memory difficulties in ASD pertains to the type of information being processed. Associative binding of components such as object features, spatial location, or temporal context must occur for an event to be correctly recalled [Giovanello, Schnyer, & Verfaellie, 2004; Russell, Cheke, Clayton, & Meltzoff, 2011; Weis et al., 2004]. If these components are not adequately processed, their relational binding and subsequent memory retrieval of an item or event may be impaired. This possible source of deficit has not been emphasized in the memory literature in ASD but may be important for a full characterization of memory in children with the disorder. Individuals with ASD may experience a global processing deficit [for review, see Happé & Frith, 2006; Happé & Booth, 2008; Van Der Hallen, Evers, Brewaeys, Van Den Noortgate, & Wagemans, 2015]. For example, Booth and Happé [2018] reported that children with ASD struggled to identify global geometric impossibilities in images and spent significantly more time viewing images before making those judgments. They concluded that their findings reflected an inability to integrate elements into a coherent whole (i.e., weak central coherence). Others have suggested that this deficit may be the result of a general dorsal stream impairment in visuospatial processing in ASD. When

compared to TD children, those with ASD experienced less central coherence and less sensitivity to global motion, both of which are indicative of higher-level dorsal stream impairments, although they exhibit comparable low-level visual processing in a flicker task [Pellicano, Gibson, Maybery, Durkin, & Badcock, 2005]. Similarly, it has been argued that motion processing inability in ASD is a result of a dorsal stream impairment [Braddick, Atkinson, & Wattam-Bell, 2003; Pellicano et al., 2005; Spencer et al., 2000; Van Der Hallen et al., 2015]. Temporal resolution processing, or the time-based interval over which integration of contextual information occurs, is also reported to be impaired in school-age children with ASD and is fundamentally important for observing and understanding events that occur across time (Foss-Feig et al., 2010) and limitations in fine-grained temporal resolution are observed in younger compared to older TD infants, underscoring a protracted developmental trajectory in the ability to perceive dynamic visual stimuli and the possibility that this trajectory may be altered in ASD [Farzin, Rivera, & Whitney, 2011]. Overall, research suggests that children with ASD may exhibit unique difficulties or delayed trajectory in their ability to process and remember spatiotemporal aspects of their memories due to their difficulty processing this information in the first place.

Previous studies have not directly compared whether children with ASD exhibit unique deficits in retrieving memory details that include spatiotemporal features versus object-specific features. However, some studies have pointed to difficulties retrieving spatial information. For example, studies of children and adults have reported deficits in memory in individuals with ASD in tasks that required retention of spatial details and spatial navigation [Lind, Bowler, & Raber, 2014; Ring, et al., 2018]. Intriguingly, recent studies have also demonstrated deficits in adults with ASD for details embedded in scene layouts [Cooper et al., 2015] and that these deficits have been linked to reduced eye movements exploring the scene during retrieval [Cooper, Plaisted-Grant, Baron-Cohen, & Simons, 2017]. These results suggest that individuals may exhibit unique deficits in retrieving spatiotemporal aspects of their memories due to their difficulty initially processing this information.

However, studies comparing retrieval of multiple details in ASD have yet to provide a complete picture. For example, Bowler et al. [2014] reported memory deficits in ASD when adults needed to retain associations between items and their spatial and color information. However, in this study, both spatial location and color were varied in every trial, which is highly demanding and makes it impossible to determine if engaging in encoding of spatial information in itself affected performance beyond the recollection of spatial information. A more recent study in adults with ASD [Bowler, Gaigg, & Gardiner, 2015] suggested deficits in both spatial and temporal details, but the tasks were not fully comparable, because spatial information was operationalized as which of three location on the screen the word had appeared (which could change on every trial), whereas temporal information was operationalized as the order of the list to which the item belonged (which necessarily could not change on every trial).

Overall, these findings do not rule out the possibility that the type of information being processed might affect the presence or magnitude of a memory deficit. Furthermore, these studies have largely assessed adult memory function in ASD. We seek to contribute to the current literature by investigating whether children with ASD and a wide range of intellectual ability levels exhibit stronger memory deficits when they retrieve item-spatial position associations compared to item-color associations. For both the color and spatial position task, we assessed item recognition and item-detail associations, allowing us to examine memory performance at different levels of retrieval demand. Thus, no obvious differences in retrieval demands existed between the color and spatial position task.

## The current study

In this study, we sought to compare the ability to remember item-context associations of children with ASD to that of TD children. We assessed participants on two separate but parallel tasks, one assessing item-spatial associations and one assessing item-color associations to rule out the possibility that processing the spatial position of a given item might interfere with processing its color context and vice versa. Each task also provided an index of item recognition memory to examine whether group differences extended beyond item-context associations. Finally, a measure of intellectual quotient (IQ) was collected to account for this additional source of variability between the groups. We expected that children with ASD would perform more poorly than TD children in memory for item-context associations and that this deficit would be stronger in the spatial compared to the color task. We expected these differences to persist even once item recognition memory and IQ were accounted for.

## Method

### *Participants*

Eighty-one children with ASD between the ages of 8 and 12 years ($M$ = 11.08, SD = 1.22) and 81 ($M$ = 11.22, SD = 1.07) TD controls were recruited for the University of California, Davis MIND Institute Autism Phenome Project (APP) and the Predictors of Cognitive Development Study (Predictors). The APP sample was originally

recruited beginning in 2006, including children between 23 and 44 months of age both with ASD and TD. Diagnostic assessments for those with ASD included the Autism Diagnostic Observation Schedule, second edition (ADOS-2) [Lord et al., 2000] and the Autism Diagnostic Interview—Revised (Lord, Rutter, & Couteur, 1994) and were carried out by licensed clinical psychologists trained to research reliability with the MIND Research Core standards. Participants with ASD met National Institutes of Health Collaborative Programs of Excellence in Autism criteria for ASD. APP participants were invited to return for a longitudinal visit when they were between 8 and 12 years of age, and diagnostic confirmation was repeated using the ADOS-2. Participants from the Predictors study were recruited starting in 2015 from the University of California, Davis MIND Institute's Subject Tracking System, fliers posted at local schools, and the surrounding Sacramento, California community. These individuals ranged in age from 8 to 12 years old. All participants from the Predictors sample had a community diagnosis of ASD, met Diagnostic and Statistical Manual of Mental Disorders, Fifth Edition (DSM-5) criteria for ASD, scored in the ASD range on the ADOS-2, and had scores of greater than 15 on the Social Communication Questionnaire (SCQ—Lifetime Edition) [Berument et al., 1999; Rutter, Bailey, & Lord, 2003]. TD participants from both studies were screened and excluded for ASD using the SCQ (scores ≥11) and all participants were administered the Differential Abilities Scales-II [DAS-II; Elliot, 2007]. Furthermore, all participants, both TD and with ASD, were native English speakers, ambulatory, and had no suspected vision or hearing problems or known genetic disorders and/or other neurological conditions. Both studies were approved by the University of California, Davis Institutional Review Board, Clinical Committee B (Protocol 686644–7) and informed consent was obtained from the parent or guardian of each participant.

Five of the participants with ASD could not complete both the spatial and color tasks because of poor comprehension of the task instructions (4 males, age mean = 11.1 years, age SD = 1.2 years, mean IQ = 68.4, mean verbal IQ [VIQ] = 59.4, mean nonverbal IQ [NVIQ] = 75). Fourteen children (7 ASD; 7 TD) were excluded due to technical difficulties with the task execution (ASD: 6 males, age mean = 11.5 years, age SD = 1.2 years, mean IQ = 84, mean VIQ = 81.3, mean NVIQ = 81.4; TD: five males, age mean = 10.7, age SD = 1.1 years, mean IQ = 106.7, mean VIQ = 108.5, mean NVIQ = 103.4). Two TD children did not complete both the color and spatial tasks due to technical difficulties. Finally, 12 children (7 ASD, 5 TD) completed only the spatial task and not the color task due to similar technical difficulties. Nine participants (ASD = 7; TD = 2) were excluded because their item-recognition performance (i.e., d′) was either at or below chance performance on one of the two tasks, preventing us from interpreting their item-context performance. All 28 of these children (23 males, mean age = 11.08 years, age SD = 1.23, mean IQ = 84.1, mean VIQ = 80.0, mean NVIQ = 85.1) were excluded from analysis and group comparisons, and this left a total sample of 62 children with ASD and 72 TD children (see Table 1).

### *Materials and Procedure*

Participants completed our memory assessment including the spatial location and color tasks. Both tasks were completed within one session, but the order of these tasks was counterbalanced across participants. At a different session, children's severity of ASD symptoms and IQ were assessed as described below.

***Memory assessment.*** Our memory task [as used in DeMaster & Ghetti, 2013; Ghetti, Lee, Sims, Demaster, & Glaser, 2010; Fig. 1] consisted of two parallel tasks, which were administered in counterbalanced order across participants. In the *spatial location task*, 80 black-ink drawings [adapted from Snodgrass & Vanderwart, 1980; standardized on central relevance to memory and cognitive processing] on a white, square background were

**Table 1. Descriptive Statistics**

| | ASD | | | Typical | | |
|---|---|---|---|---|---|---|
| | 62 | | | 72 | | |
| n | Mean | SD | Range | Mean | SD | Range |
| Age | 11.00 | 1.21 | 8.82–13.62 | 11.25 | 1.08 | 8.00–13.65 |
| Gender (% male) | 49 (79.0%) | – | – | 51 (70.8%) | – | – |
| ADOS severity | 6.74 | 1.94 | 1.0–10.0 | – | – | – |
| ADOS repetitive behaviors | 2.97 | 1.60 | 0.0–6.0 | – | – | – |
| ADOS social affect | 8.60 | 3.12 | 2.0–17.0 | – | – | – |
| Full-scale IQ | 100.53 | 18.53 | 63.0–170.0 | 112.29 | 12.51 | 83.0–140.0 |
| Verbal IQ | 98.97 | 22.28 | 49.0–157.0 | 113.63 | 10.54 | 86.0–140.0 |
| Nonverbal IQ | 100.55 | 17.42 | 66.0–170.0 | 108.19 | 14.04 | 81.0–143.0 |

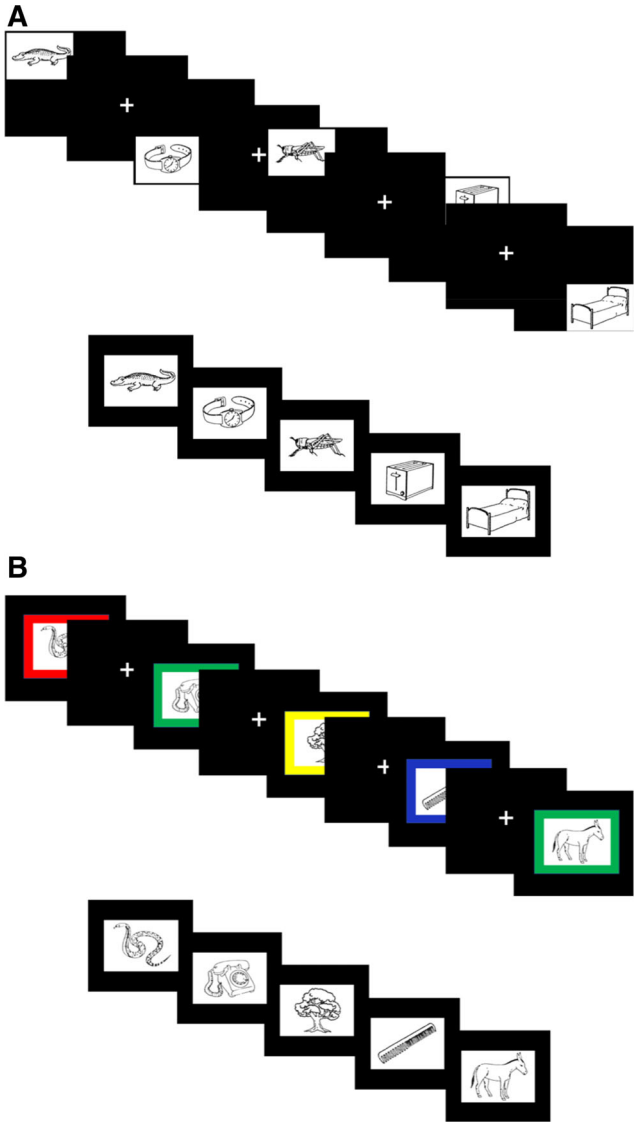


**Figure 1.** (A) Space-context item stimuli presentation and retrieval and (B) Color-context item stimuli and retrieval.

presented on a 30.96 cm by 17.46 cm computer screen in one of the four quadrants of the computer screen (20 of each location in a random order). Images were 7.30 cm × 7.30 cm and approximately 4.76 cm from center fixation. Participants sat approximately 30.5 cm from the screen and were instructed to try to remember both the item and the location that it appeared. Each drawing was displayed for 1 sec, followed by a 1-sec interval in which a fixation point was presented. Participants then were given a self-paced recognition test including 80 studied drawings and 80 new drawings presented in random order. During the recall portion of the task, drawings were presenting in the middle of the screen. Participants first determined whether or not they had seen the drawing before. Only when a drawing was recognized did participants report the spatial location where that drawing was presented.

The *color* task was identical to the spatial task, except that the drawings did not vary in their location on the screen but instead were presented in the middle of the screen with either a green, red, yellow, or blue border around the drawing (20 of each color in a random order). Thus, participants were instructed to remember both the item and color of its border and were then tested on their memory for the association between drawing and color border. Each memory task took approximately 25 min, and a 30-min break was given between them. Drawings for each task were chosen from a set of 320 unambiguous line drawings; these materials were previously normed with child participants for familiarity, visual complexity, and name agreement. Use of drawings in the color versus spatial location and task order were counterbalanced across participants.

Each of the memory tasks was designed to provide several indices of memory performance; these include item-context association rate and $d'$. The item-context association rate is the rate of correct item-color and item-spatial location associations recollected over the total of previously viewed items correctly recognized. Conversely, $d'$ [Macmillan & Creelman, 2004] corresponds to the normalized difference between distribution of hit rates, or the correct naming of an item that was seen previously, and the distribution of false-alarm rates, or the incorrect naming of an item as being seen previously when it was not. The measure of $d'$ reflects the ability to discriminate between old and new items and varies from 0 (no ability to discriminate) to 4 (nearly perfect ability to discriminate). These tasks are sensitive to subtle difficulties with memory for item-context associations as demonstrated in previous studies documenting children's memory deficits following diabetic ketoacidosis [Ghetti et al., 2010] and general anesthesia [Stratmann et al., 2014].

***Assessment of severity autism spectrum disorder symptoms.*** Participants with ASD completed the ADOS-2. The ADOS is a semi-structured interactive session and interview protocol that provides opportunities for the child to display a number of social, communicative, and stereotyped behaviors [Lord et al., 2012]. Depending on an individual's language level and age, they were administered one of several modules of the ADOS-2, in this sample, 1 was administered Module 2 (1.6%), and 61 were administered Module 3 (98.4%). ADOS Calibrated Severity Score (CSS) was calculated and allows for comparison of severity of symptoms across different modules [Gotham, Pickles, & Lord, 2012].

***IQ measure.*** IQ was assessed via the DAS-II. Verbal Reasoning, Nonverbal Reasoning, and General Conceptual Ability scales provided estimates of VIQ, NVIQ, and full-

scale IQ. Participants completed the core battery of the DAS-II Upper Early Years or School Age form. The mean of these two measures was used as an estimate of overall IQ.

## Results

This memory assessment has been used in numerous other studies [DeMaster & Ghetti, 2013; Ghetti et al., 2010; Kuppermann et al., 2018]. There were strong correlations in performance between the first and the second half of the task in both color, $r(132) = 0.66$, $P < 0.001$, and space, $r(132) = 0.75$, $P < 0.001$, for $d'$, which is the more comprehensive measure given that all participants are asked the same questions, unlike item-context association, which depends on a correct answer of whether the item has been previously seen in order to be answered.

First, analyses were conducted with a series of univariate analysis of variance to determine if there were any differences between individuals with ASD and TD children in age and IQ. There was no group difference in age, $t(123.4) = -1.56$, $P = 0.12$, but children with ASD showed lower IQ, $t(104.42) = -4.23$, $P < 0.001$ (see Table 1).

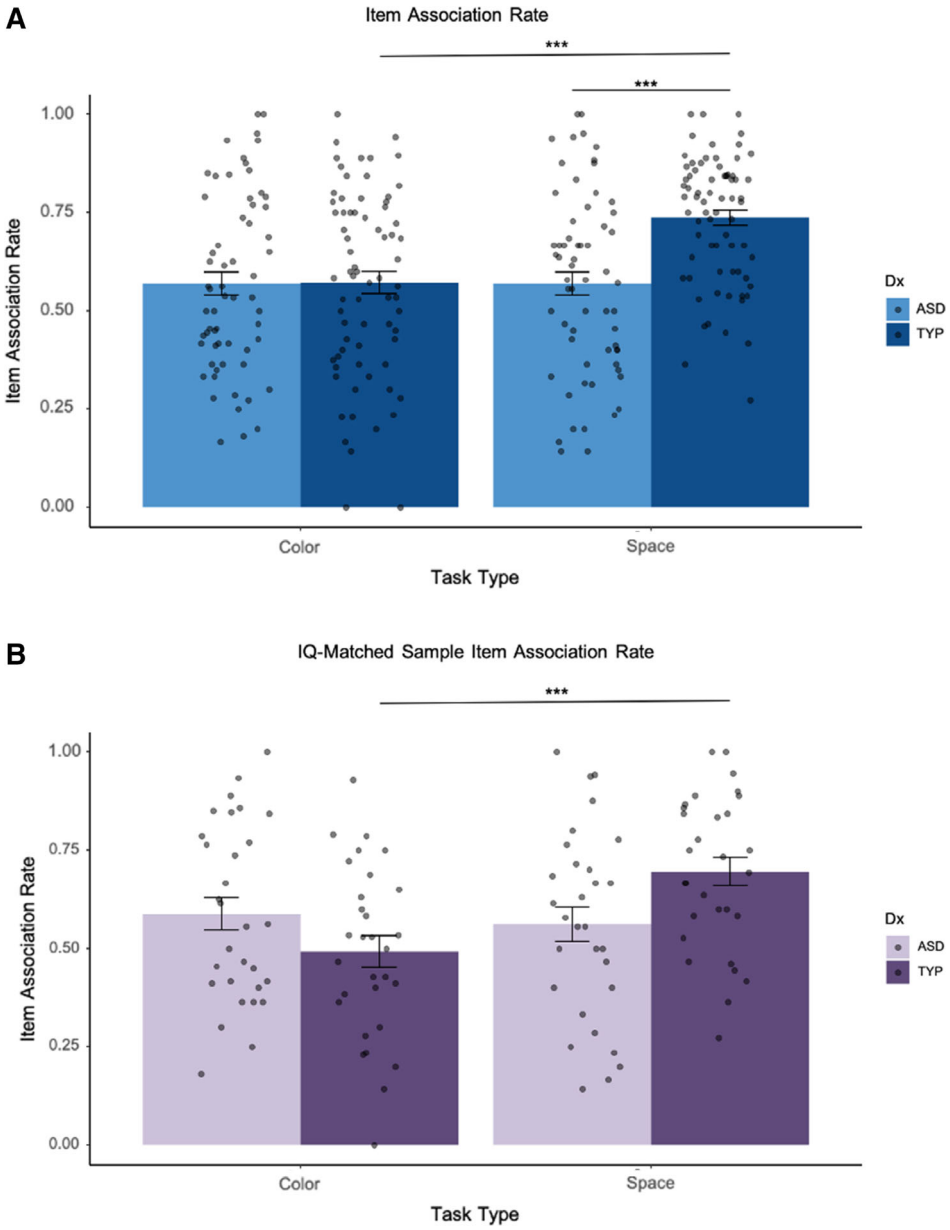


**Figure 2.** (A) Full sample Item-Context Association Rate as a function of participant group and type of task (spatial-context or color-context) and (B) IQ-matched sample of Item-Context Association Rate as a function of participant group and type of task.

Item-context association and $d'$ were positively correlated in the ASD group for both the color, $r(60) = 0.52$, $P < 0.001$, and space, $r(60) = 0.41$, $P < 0.005$, tasks, as well as in TD for both the color, $r(70) = 0.35$, $P < 0.005$, and space, $r(70) = 0.43$, $P < 0.001$, tasks.

The hypothesis that individuals with ASD exhibited memory deficits compared to TD children was tested with a series of 2 (group: ASD vs. TD) × 2 (task: spatial vs. color) mixed analysis of variances (ANOVA) with item association rate and $d'$ entered as the dependents measures. Since participants were not matched for intellectual ability, full-scale IQ was included as covariate in corresponding analysis of covariances (ANCOVA). Age was also used as a covariate to eliminate age-related memory improvements as a contributing factor in our results.

The 2 (group: ASD vs. TD) × 2 (task: spatial vs. color) mixed ANOVA on rate of correct item-context associations revealed a significant main effect of group, $F(1, 132) = 7.68$, $P < 0.01$, $\eta_p^2 = 0.04$, such that children with ASD performed worse, $M = 0.57$, SD = 0.23, than did TD children, $M = 0.65$, SD = 0.22. There was also a significant main effect of task, $F(1, 132) = 15.25$, $P < 0.001$, $\eta_p^2 = 0.04$, such that children generally recollected fewer item-color, $M = 0.57$, SD = 0.23, compared to item-space associations, $M = 0.66$, SD = 0.21. Critically, there was also a significant group by task interaction, $F(1, 132) = 15.03$, $P < 0.001$, $\eta_p^2 = 0.04$ (Fig. 2A), revealing that the deficits in the ASD group were restricted to the spatial task. This interaction persisted when we included $d'$, age, and IQ as covariates, $F(1, 128) = 16.51$, $P < 0.001$, $\eta_p^2 = 0.05$. This ANCOVA continues to show a main effect of task, $F(1, 128) = 5.18$, $P < 0.05$, $\eta_p^2 = 0.02$, and additionally revealed an effect of space $d'$, $F(1, 128) = 19.90$, $P < 0.001$, $\eta_p^2 = 0.09$; as well as significant interactions between age and task, $F(1, 128) = 4.71$, $P < 0.05$, $\eta_p^2 = 0.01$, and color $d'$ and task type, $F(1, 128) = 6.20$, $P < 0.05$, $\eta_p^2 = 0.02$. We found no correlation between ADOS-2 CSS and item-context association, $r(60) = 0.20$, $P = 0.12$, for participants with ASD.

Given that $d'$ was associated with item-context performance, we conducted a 2 (group: ASD vs. TD) × 2 (task: spatial vs. color) mixed ANOVA with $d'$ as the dependent measure (see Table 2 for hit and false alarm rates). We again found a significant main effect of group, $F(1, 132) = 9.80$, $P < 0.01$, $\eta_p^2 = 0.05$, such that children with ASD performed worse, $M = 2.13$, SD = 1.06, than TD children, $M = 2.55$, SD = 0.74. There was also a significant effect of task, $F(1, 132) = 12.74$, $P < 0.001$, $\eta_p^2 = 0.02$, such that performance was lower in the spatial task, $M = 2.22$, SD = 0.98, compared to the color task, $M = 2.50$, SD = 0.84. With respect to $d'$, there was no significant group by task interaction, $F(1, 132) = 0.01$, $P = 0.92$, $\eta_p^2 = 0.000$ (Fig. 3A).

**Table 2. Group Means and Standard Deviations (SD) for Memory Tasks of Full Sample**

| | ASD | | Typical | |
|---|---|---|---|---|
| | Color | Spatial | Color | Spatial |
| Hit rate | | | | |
| Mean | 0.71 | 0.62 | 0.77 | 0.72 |
| SD | 0.20 | 0.27 | 0.16 | 0.17 |
| Range | 0.25–1.00 | 0.10–1.00 | 0.35–1.00 | 0.25–1.00 |
| False alarm rate | | | | |
| Mean | 0.07 | 0.08 | 0.02 | 0.04 |
| SD | 0.16 | 0.14 | 0.06 | 0.08 |
| Range | 0.00–0.85 | 0.00–0.70 | 0.00–0.50 | 0.00–0.50 |
| d′ | | | | |
| Mean | 2.28 | 1.99 | 2.69 | 2.42 |
| SD | 0.96 | 1.13 | 0.67 | 0.79 |
| Range | 0.13–3.92 | 0.15–3.92 | 0.52–3.92 | 0.13–3.92 |
| Item association rate | | | | |
| Mean | 0.57 | 0.57 | 0.57 | 0.74 |
| SD | 0.22 | 0.23 | 0.24 | 0.16 |
| Range | 0.17–1.00 | 0.14–1.00 | 0.00–1.00 | 0.27–1.00 |

When age and IQ were used as covariates in this analysis, the significant main effect of group became marginal, $F(1, 130) = 3.51$, $P = 0.06$, $\eta_p^2 = 0.02$, but the effect of task was lost, $F(1, 130) = 0.06$, $P = 0.81$, $\eta_p^2 = 0.001$. There was, however, a main effect of IQ, $F(1, 130) = 6.39$, $P < 0.05$, $\eta_p^2 = 0.03$, and a marginal effect of age, $F(1, 130) = 3.73$, $P = 0.056$, $\eta_p^2 = 0.02$, when age and IQ were used as covariates in the $d'$ analysis. Indeed, IQ was significantly correlated with both color $d'$, $r(132) = 0.36$, $P < 0.001$, and space $d'$, $r(132) = 0.20$, $P < 0.05$, and the magnitude of the two correlations is not statistically different ($z = 1.43$, $P = 0.07$). Finally, we found no correlation between ADOS-2 CSS and $d'$, $r(60) = 0.07$, $P = 0.59$.

Although we controlled for IQ in all of the reported analyses above, there is still the possibility that the ANCOVA analysis cannot fully account for the existing group differences in IQ. A complementary approach is to compare performance on a selected subset of participants who are matched on IQ (see Table 3). In an IQ-matched subset, there was no difference between the ASD and TD groups in IQ, $t(1, 57.97) = -0.57$, $P = 0.57$ (see Table 4). The 2 (group: ASD vs. TD) × 2 (task: spatial vs. color) mixed ANOVA on rate of correct item-context associations revealed no main effect of group, $F(1, 58) = 0.16$, $P = 0.69$, $\eta_p^2 = 0.002$. There was a significant main effect of task, $F(1, 58) = 8.27$, $P < 0.01$, $\eta_p^2 = 0.04$. There was also a significant group by task interaction, $F(1, 58) = 13.97$, $P < 0.001$, $\eta_p^2 = 0.07$ (Fig. 2B). When we included $d'$ and age as covariates, the primary interaction held, $F(1, 54) = 13.97$, $P < 0.001$, $\eta_p^2 = 0.07$, as well as the main effect of task, $F(1, 54) = 8.27$, $P < 0.01$, $\eta_p^2 = 0.04$. There was no main effect of group, $F(1, 54) = 0.16$, $P = 0.69$,

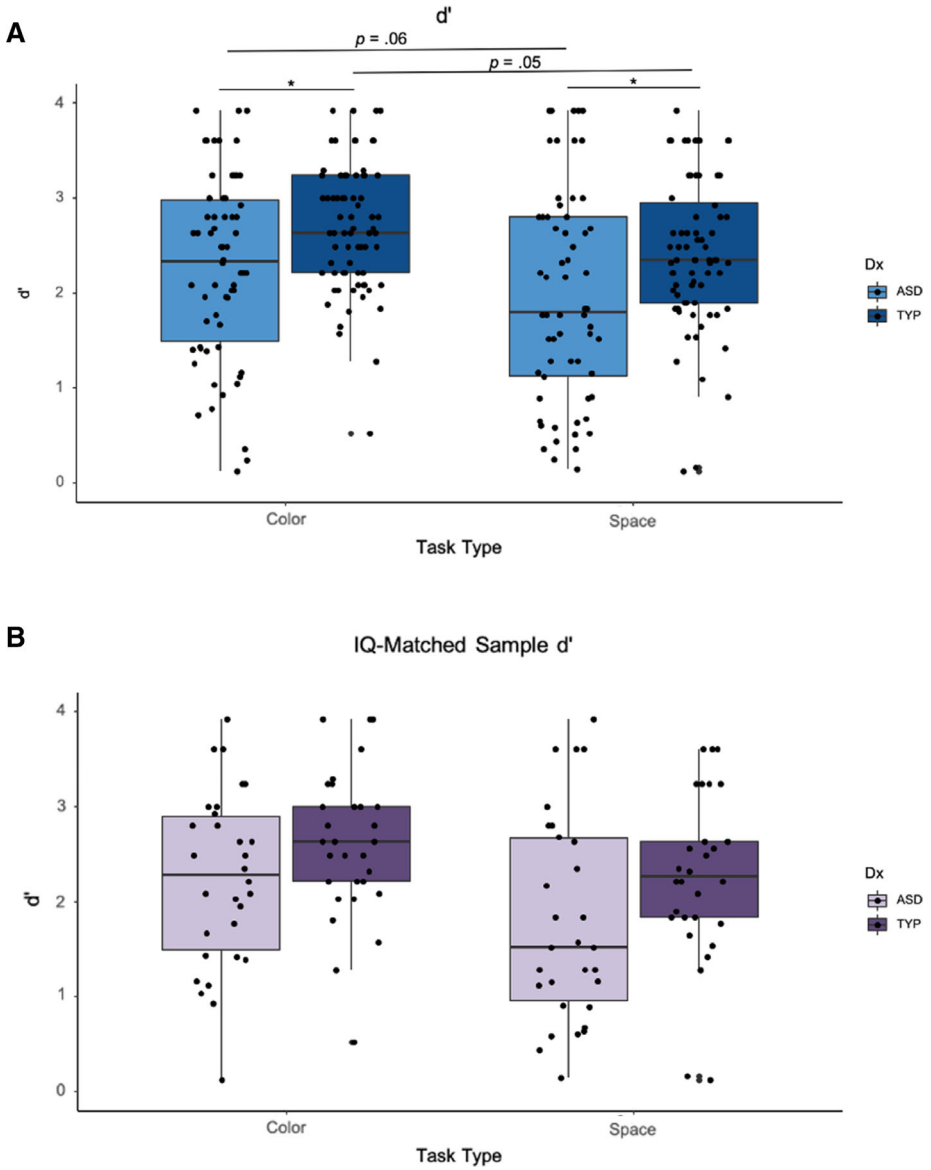


**Figure 3.** (A) Full sample *d′* as a function of participant group and type of task (spatial context or color context) and (B) IQ-matched sample of d′ as a function of participant group and type of task.

$\eta_p^2 = 0.002$. When *d′* and age were used as covariates, there were also main effects of space *d′*, $F(1, 54) = 12.68$, $P < 0.001$, $\eta_p^2 = 0.13$, and color *d′*, $F(1, 54) = 4.65$, $P < 0.05$, $\eta_p^2 = 0.05$. There was no correlation between item-context association and ADOS-2 CSS, $r(28) = 0.21$, $P = 0.27$, for participants with ASD.

In our IQ-matched sample, we also conducted the 2 (group: ASD vs. TD) × 2 (task: spatial vs. color) mixed ANOVA with *d′* as the dependent measure. We found both a significant main effect of group in this sample, $F(1, 58) = 4.81$, $P < 0.05$, $\eta_p^2 = 0.05$, and a main effect of task, $F(1, 58) = 8.68$, $P < 0.005$, $\eta_p^2 = 0.05$. We did not find a significant group by task interaction, $F(1, 58) = 0.15$, $P = 0.70$, $\eta_p^2 = 0.0008$ (Fig. 3B). When age was used as a covariate in this analysis, the main effect of group held, $F(1, 57) = 4.08$, $P < 0.05$, $\eta_p^2 = 0.05$. There was no longer a significant main effect of task, $F(1, 57) = 0.13$, $P = 0.72$, $\eta_p^2 = 0.0007$, or group by task interaction, $F(1, 57) = 0.22$, $P = 0.64$, $\eta_p^2 = 0.001$. Finally, we found no correlation between ADOS-2 CSS and *d′*, $r(28) = 0.09$, $P = 0.63$. Critically, while results varied between the full sample and the IQ matched sample, we reaffirmed the main result of this study, namely, that children with ASD exhibited a selective deficit in item-spatial memory and not in item-color memory. This is particularly influential given the lack of group differences in d′, indicating that memory

impairment in ASD is limited to recollection of spatial features and not item familiarity.

To verify that the results of the original ANCOVA model did not depend on a particular component of IQ, we tested our covariate models using VIQ and NVIQ in place of full-scale IQ. There was no change in the pattern of results for item-context association model when either VIQ or NVIQ was substituted for general IQ (see Data S1).

## Discussion

The goal of the present study was to investigate the capacity to remember item-context associations in children with ASD. Our sample was relatively large and heterogeneous in intellectual ability. We expected that children with ASD would exhibit a differential pattern of strengths and weaknesses with regard to episodic memory. Specifically, we predicted decreases in performance relative to TD children on a spatial, rather than color-association task. Item-context associations are instrumental to episodic memory because they establish a unique representation of an item or event and the surrounding details in which it occurred.

Results were consistent with our predictions. It is important to note that the spatial task was not more difficult than the color task for TD children. This eliminates the possibility that general task difficulty is responsible for the differences shown in ASD. Critically, the specific deficit in item-space association memory persisted even when the analyses accounted for item recognition memory, age, and IQ, underscoring that general cognitive abilities cannot easily explain this result. This study extends the current knowledge surrounding the development of episodic memory in children with ASD and identifies the type of information to be recalled as an important factor in understanding episodic memory difficulties in children with ASD.

One reason that spatial-context binding may be more difficult for individuals with ASD is that deficits in visuospatial processing may be a component of the disorder, namely, those associated with the dorsal stream [Bertone, Mottron, Jelenic, & Faubert, 2005]. This is consistent with experiments of impaired visual long-term memory in children with ASD [Jiang, Palm, DeBolt, & Goh, 2015]. Similarly, deficits in scene layout retrieval supported by reduced eye movements [Cooper et al., 2015, 2017] imply that those with ASD may be experiencing selective difficulty when processing complex visual stimuli, consistent with theories of weak central coherence. Intriguingly, other studies have suggested that memory for complex visual scenes is more impaired in ASD when participants experience the scene in the third person and an allocentric representation of the scene is necessary compared to the first person [i.e., egocentric; Ring, et al., 2018]. Allocentric representation has long been considered a signature of hippocampal function [e.g., Lavenex & Banta-Lavenex, 2013], underscoring difficulty with memory mechanisms supported by the

**Table 3. Group Means and Standard Deviations for Memory Tasks of IQ-matched Sample**

| | ASD | | Typical | |
|---|---|---|---|---|
| | Color | Spatial | Color | Spatial |
| Hit rate | | | | |
| Mean | 0.71 | 0.56 | 0.76 | 0.68 |
| SD | 0.18 | 0.27 | 0.16 | 0.19 |
| Range | 0.30–1.00 | 0.10–1.00 | 0.35–1.00 | 0.25–0.95 |
| False alarm rate | | | | |
| Mean | 0.08 | 0.08 | 0.03 | 0.05 |
| SD | 0.16 | 0.16 | 0.09 | 0.10 |
| Range | 0.00–0.70 | 0.00–0. 70 | 0.00–0.50 | 0.00–0.50 |
| *d′* | | | | |
| Mean | 2.24 | 1.79 | 2.61 | 2.27 |
| SD | 0.91 | 1.08 | 0.78 | 0.88 |
| Range | 0.13–3.92 | 0.15–3.92 | 0.52–3.92 | 0.23–3.60 |
| Item association rate | | | | |
| Mean | 0.59 | 0.56 | 0.49 | 0.67 |
| SD | 0.23 | 0.24 | 0.22 | 0.20 |
| Range | 0.18–1.00 | 0.14–1.00 | 0.00–0.93 | 0.27–1.00 |

**Table 4. IQ-matched Sample Descriptives**

| | ASD | | | Typical | | |
|---|---|---|---|---|---|---|
| | 30 | | | 30 | | |
| *n* | Mean | SD | Range | Mean | SD | Range |
| Age | 11.00 | 1.08 | 8.08–13.65 | 11.33 | 0.98 | 8.08–13.62 |
| Gender (% male) | 24 (80%) | – | – | 20 (67%) | – | – |
| ADOS severity | 6.77 | 2.24 | 1.0–10.0 | – | – | – |
| ADOS repetitive behaviors | 2.8 | 1.67 | 0.0–6.0 | – | – | – |
| ADOS social affect | 8.8 | 3.69 | 2.0–17.0 | – | – | – |
| Full-scale IQ | 99.6 | 6.60 | 91.0–110.0 | 100.6 | 6.46 | 83.0–109.0 |
| Verbal IQ | 98.3 | 13.97 | 70.0–120.0 | 107.33 | 10.65 | 86.0–130.0 |
| Nonverbal IQ | 98.3 | 9.79 | 83.0–119.0 | 96.47 | 7.62 | 81.0–108.0 |

hippocampus, although other studies highlight impoverished spontaneous use of landmark cues in ASD [Ring, Gaigg, de Condappa, Wiener, & Bowler, 2018], suggesting that environmental support may at least in part alleviate difficulties with spatial memory in children with ASD.

An alternative account of deficits in item-context associative binding is the theory of enhanced perceptual functioning (EPF). Specifically, EPF states that ASD is not characterized by an inability to bind or integrate contextual features into a single episodic event, but rather a superior ability to differentiate elements of said event. The EPF account claims that local processing is enhanced (and may be of greater focus), but not at the expense of global processing of information. The theory is consistent with claims of improved performance in ASD compared to TD individuals on first-order spatial tasks [Mottron, Dawson, Soulières, Hubert, & Burack, 2006]. This enhanced ability is marked by superior pattern separation and detection, particularly when stimuli are crowded. In some visuospatial tasks, children with ASD significantly outperform their TD peers [Kéta, Mottron, Dawson, & Bertone, 2011; Mottron, Dawson, & Soulières, 2009]. However, the EPF theory may not apply to tasks that are considered to require more complex or higher-level spatial processing and the dorsal stream, due to the theory's focus on low-level cognitive tasks. In particular, our stimuli did not present an opportunity for pattern detection due to its focus on item recognition and associated item-context.

We note that there were also group differences in item recognition memory, such that children with ASD performed worse than their TD counterparts. It is possible that memory deficits in childhood extend beyond their episodic component. This would be in line with the idea that development brings about compensatory mechanisms that might mitigate memory impairments [Livingston & Happé, 2017; Solomon, McCauley, Iosif, Carter, & Ragland, 2016; Zalla & Korman, 2018]. These group differences were still present when age and IQ were statistically accounted for, suggesting that item recognition is also impaired in ASD. However, these group differences disappeared in our IQ-matched sample suggesting that item familiarity is not intrinsically impaired in ASD, but impaired recollection of spatial features may be a hallmark specific to ASD. Thus, given that item-space association deficits were observed after controlling for item recognition and no deficits in item-color association were found, we can still point to a selective deficit in episodic retrieval for details about the spatial context of the memory. Finally, because the color and space tasks are comparable in terms of their design and retrieval demands, our findings cannot be clearly explained by task demands.

In terms of neural substrates, altered hippocampal structure and function have been reported in ASD [Reinhardt et al., 2019]. It has also been reported that there is a correlation between autistic traits/symptomatology and gray matter density within the hippocampus [Salmond et al., 2005]. However, given that our results do not indicate an impairment in all contexts of recall in episodic memory, something more than a hippocampal impairment might underlie episodic memory differences in children with ASD. Future research should examine more specifically the connection between dorsal stream processing dysfunction and episodic memory ability. Namely, while the hippocampus supports all aspects of binding items to contexts [Preston & Eichenbaum, 2013], numerous other structures are needed for both encoding and retrieval of said contexts. For example, the associative cortices in the dorsal stream respond to spatial relationships and layouts [Kravitz, Saleem, Baker, & Mishkin, 2011] and if deficits are observed there, we should expect memories that are less rich in the same type of detail. Whether episodic memory impairment is primarily an encoding or retrieval deficit in ASD has yet to be determined [Brezis, Galili, Wong, & Piggot, 2014], but future studies manipulating these factors will elucidate the role of these information processing phases.

It is important to note that while results were consistent with our predictions, our effect sizes were not large and memory performance (on both $d'$ and item-context association) was not significantly correlated with measures of ASD symptoms. This may be because the phenotypic presentation and experience of ASD is quite heterogeneous. It is, therefore, possible that spatial-context memory impairment is not a core difficulty in ASD (i.e., not experienced by all individuals with ASD), but rather a feature in some specific subgroups. Future categorization of genetic and behavioral subcategories of ASD may effectively reframe the presence or omission of spatial-context memory impairment.

Future research is needed to differentiate contextual-binding impairments from context retrieval issues, particularly assessing the utilization of the dorsal stream and other complex processing neuromechanisms directly via functional neuroimaging. A limitation of this study is that the completion of these memory tasks requires a relatively high level of understanding of verbal instruction. Thus, we cannot generalize these findings to the full spectrum of ASD functioning. Nevertheless, our results indicate that examining memory deficits as a function of the type of information recollected may be a promising venue for future research.

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## Supporting Information

Additional supporting information may be found online in the Supporting Information section at the end of the article.

**DATA S1** VIQ and NVIQ analyses.