Visual working memory performance is intact across development in autism spectrum disorder

Andrew Lynn¹, Beatriz Luna² & Kirsten O'Hearn³

¹Department of Psychology & Human Development, Peabody College, Vanderbilt University

²Department of Psychology, University of Pittsburgh

³Department of Physiology and Pharmacology, Wake Forest University

Author Note

Andrew Lynn, ORCID: <https://orcid.org/0000-0003-3822-2672>

Beatriz Luna, ORCID: <https://orcid.org/0000-0002-9929-2458>

Kirsten O'Hearn, ORCID: <https://orcid.org/0000-0003-3427-5304>

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Correspondence concerning this article should be addressed to Dr. Andrew Lynn, Department of Psychology and Human Development, Vanderbilt University. Email:

Andrew.Lynn.1@Vanderbilt.edu

Abstract

Autism Spectrum Disorder (ASD) is associated with atypical visual processing and deficits in working memory (WM). Visual WM performance typically improves between childhood and adulthood, but such improvement may be atypical in ASD. To better understand how visual WM develops, we used a well-established change detection task across multiple visual features. We examined visual WM for *color*, *shape* and *pattern* in children, adolescents, and adults with and without ASD. VWM capacity and performance for all visual features improved across age similarly for both the TD and ASD groups. While performance was better on Set Size 4 trials than Set Size 8 trials for color, shape, and no change trials, such an effect was not evident for pattern change trials. Overall, the present findings suggest that VWM for different visual features may be intact across development in ASD.

Lay Abstract

The ability to hold multiple objects in mind (working memory) improves across typical development, but it remains unclear whether such improvement occurs in Autism Spectrum Disorder (ASD). We found that developmental improvements in working memory for different types of object details (e.g., color, shape, pattern) is generally similar for both ASD and typical development.

Keywords: Autism, visual processing, working memory, child development, attention

Introduction

Autism Spectrum Disorder (ASD) is often associated with atypical visual processing (Behrmann et al., 2006; Happé & Frith, 2006; Mottron et al., 2006) and deficits in spatial working memory (WM; Kercood et al., 2014; O'Hearn et al., 2008; Wang et al., 2017). They also exhibit other memory impairments, including recognition memory for faces (Griffin et al., 2021; O'Hearn et al., 2010; Weigelt et al., 2012), objects (Blair et al., 2002; O'Hearn et al., 2014), and scenes (Cooper et al., 2015; O'Hearn et al., 2011; Williams, Goldstein, & Minshew, 2005). These memory impairments sometimes are evident as a truncated developmental trajectory, with improvements arrested in adolescence (Andersen et al., 2015; Kuschner et al., 2009; O'Hearn et al., 2010, 2011, 2014). Here, we focus on visual WM (VWM; also called visual short-term memory) in which a visual feature or features are maintained in mind over a short delay (Astle & Scerif, 2011). Specifically, we examine whether age-related changes in VWM differ between typically developing (TD) individuals and those with ASD.

Extensive research also shows that spatial WM performance is usually poorer in ASD relative to their TD peers (see Desautay et al., 2020; Kercood et al., 2014; Wang et al., 2017). While some studies have found typical performance in ASD across development (Ozonoff & Strayer, 2001), many have found that individuals with ASD display poor spatial WM performance compared to TD individuals in childhood (Cui et al., 2010; Geurts et al., 2004; Zinke et al., 2010), adolescence (Williams et al., 2006; Williams, Goldstein, Carpenter, et al., 2005), and adulthood (Funabiki & Shiwa, 2018; Williams, Goldstein, Carpenter, et al., 2005). Similar to the pattern of recognition memory abilities across development in ASD, one study found both a pervasive spatial WM deficit across development in ASD and an increase in this deficit in from adolescence to adulthood, with improvements in the TD group but not the ASD group (Luna et al., 2007).

One underlying mechanism that may link deficits and atypical development in recognition memory and spatial WM is disrupted visual processing (Bakroon & Lakshminarayanan, 2016; Behrmann et al., 2006; Happé & Frith, 2006; Mottron et al., 2006). It is unclear whether VWM abilities for visual features, that together build scenes and complex objects such as faces, are disrupted in ASD and whether improvement in VWM for these features follows a similar developmental trajectory in ASD as recognition memory and spatial WM. Relative to TD, children and adolescents with ASD exhibit poorer VWM performance and a smaller VWM capacity for the *location* of simple shapes (Jiang et al., 2013). Evidence from TD children suggests that more autistic-like traits are associated with better detection of subtle shape changes in a VWM task (Hamilton et al., 2018). Typical adults with more autistic-like “attention-to-detail” traits (but not more “social interaction” traits) have a larger VWM capacity for visually complex items (Richmond et al., 2013). Together these findings suggest that individuals with ASD may be better at holding visual *details* in WM relative to simple shapes and locations (or spatial relations among items) across the visual field. This is consistent with theories that individuals with ASD preferentially process local features of a scene instead of the overall configuration (e.g., weak central coherence; Happé & Frith, 2006). So, in contrast to the spatial WM studies, change detection studies suggest that people with ASD may be better than TD groups in holding visual features in WM, especially small details (e.g., pattern) compared to larger features (e.g., shape).

Here, we examine VWM development using a change detection paradigm, in which participants are asked to remember a visual feature of an object (e.g., color). First, participants are briefly presented with a sample array of items (e.g., 8 colored squares) and then one item alone in a previous location, either the same or different as the sample array (Awh et al., 2007). This task has revealed that adults hold about 4 items in WM (e.g., Luck & Vogel, 1997), and that WM

capacity may depend on the visual complexity of the items and the array in which they are presented (Alvarez & Cavanagh, 2004; Eng et al., 2005; but see, Awh et al., 2007; Vogel et al., 2001). Adults hold fewer details within an item (e.g., pattern of lines filling a shape) in WM relative to the item shape (e.g., oval or rectangle) (Fukuda et al., 2010). Developmentally, VWM performance typically improves between childhood and adulthood (e.g., Cowan et al., 2006; Cowan, Sauls, et al., 2015), and may reflect an increase in VWM *capacity*. (Cowan et al., 2010; Cowan, Ricker, et al., 2015; Riggs et al., 2006; Simmering, 2012). However, it is unclear whether VWM in ASD improves similarly across development.

We tested children, adolescents, and adults with and without an ASD diagnosis on two change detection tasks in which we measured VWM abilities for simple colored squares (Awh et al., 2007) and for shapes and the line patterns that filled each shape (Fukuda et al., 2010). We chose to bin participants into age groups because we expected that age-related changes may be linear in TD but non-linear in ASD (e.g., Luna et al., 2007; O’Hearn et al., 2010). We examined whether the age-related changes in VWM capacity and performance differed between those with and without ASD. We predicted that 1) both capacity and performance would improve with age in both groups, but 2) these age-related improvements might be less evident in the ASD group, especially from adolescence to adulthood. In line with the ‘weak central coherence’ hypothesis of ASD (Happé & Frith, 2006), we also predicted that the ASD group would perform better and have a larger VWM capacity for pattern changes relative to their TD peers, but the TD group would perform better and have a larger VWM capacity for shape and color changes.

Methods

Participants

The ASD group consisted of 24 children, 22 adolescents, and 20 adults, and the TD group consisted of 25 children, 24 adolescents, and 31 adults. See Table 1 for a full description of participant demographics and diagnostics. The racial make-up of our final sample was as follows: 91.1% White, 5.5% Black, 0.7% Multiracial, and 2.7% declined to answer. Our sample was 91.1% non-Hispanic, 0.7% Hispanic, and 8.2% declined to answer. Participants had no history of head injury, birth injury, or seizure disorder, and all participants had normal or corrected-to-normal vision. Participants completed a battery of experimental behavioral tasks that measured VWM performance. We measured participant's IQ using the Wechsler Abbreviated Scale of Intelligence (WASI; Wechsler, 1999). We excluded participants with a full-scale IQ (FSIQ) score of less than 70. Within the child group only, performance IQ was slightly higher in group with ASD compared to TD group ($p = 0.029$). The present study was prospectively reviewed and approved by the University of Pittsburgh IRB. Parents and adults provided consent, and children and adolescents provided their assent.

Participants with ASD were recruited through the University's Autism Center of Excellence (ACE) subject core (HD #055748). Autism diagnoses were determined based on Diagnostic and Statistical Manual of Mental Disorders criteria (*Diagnostic and Statistical Manual of Mental Disorders : DSM-IV*, 2000) using the Autism Diagnostic Observation Schedule (ADOS; Lord et al., 1989) and the Autism Diagnostic Interview–Revised (ADI-R; Lord et al., 1994) and were confirmed by expert clinical assessment. Individuals in the group with ASD met cut-offs for autism on the ADI-R (except one individual on section D, Abnormality of Development Evident at or Before 36 Months) and for autism or ASD on the ADOS.

One TD adolescent and one TD adult, as well as three adolescents with ASD completed testing but were excluded because at least one performance measure was more than 3 times the interquartile range of their respective Diagnosis group and Age group mean. All participants in the final sample completed the Color task, describe below. Most of the final sample also completed

Table 1. Participant demographics

Variable	Children (7 - 12 years old)			Adolescents (13 - 17 years old)			Adults (18 - 36 years old)		
	TD (n = 25)	ASD (n = 24)		TD (n = 24)	ASD (n = 22)*		TD (n = 31)	ASD (n = 20)	
	<i>M (SD)</i>	<i>M (SD)</i>	<i>t(47), p</i>	<i>M (SD)</i>	<i>M (SD)</i>	<i>t(44), p</i>	<i>M (SD)</i>	<i>M (SD)</i>	<i>t(49), p</i>
Sex	19 Males	22 Males		20 Males	18 Males		28 Males	19 Males	
Age (years)	11.25 (1.38)	11.23 (1.71)	.035, .972	15 (1.41)	15.27 (1.48)	-.639, .526	24.42 (5.31)	24.12 (4.76)	.208, .836
FSIQ	107 (12.1)	113.1 (12.8)	-1.726, .09	107.7 (8.3)	107.2 (13.6)	.146, .884	113.5 (11.4)	110.8 (14.4)	.739, .464
VIQ	105.1 (10.5)	108.3 (13.1)	-.937, .353	107.6 (11.7)	106.2 (13.5)	.377, .708	111.2 (11.4)	110.1 (12.7)	.343, .733
PIQ	107.1 (13)	115.5 (13.2)	-2.251, .029*	106.4 (8.7)	106.3 (13.8)	.017, .987	112.8 (11.8)	109.2 (16.2)	.930, .357
ADOS									
Communication		3.4 (1.4)			3.9 (1.2)			4.3 (1.5)	
Social		7.8 (2)			7.7 (2.1)			8.5 (2.5)	
Full-scale		11.3 (3.2)			11.5 (3)			12.8 (3.5)	
ADI-R									
Communication		16 (3.8)			15.2 (4.1)			16.8 (4)	
Social		18.6 (5.7)			19.9 (5.5)			22.2 (3.6)	
Behavior		6.4 (2.1)			6.1 (2.3)			6.4 (2.5)	
Abnormality		3.2 (1.3)			2.8 (1.7)			3 (1.1)	

*One ASD adolescent did not have complete diagnosis data

TD = typically developing; ASD = Autism Spectrum Disorder; FSIQ = Full Scale IQ; VIQ = Verbal IQ; PIQ = Performance IQ

the Shape and Pattern task, except for one TD child and one TD adult, as well as three children and one adult with ASD.

Procedure

Participants completed a battery of tasks over the course of ~2 hours. The present study examines data from two of these tasks; a color change detection task (Awh et al., 2007) and a shape/pattern change detection task (Fukuda et al., 2010). Together, these tasks took about 30 to 45 minutes. Participants were first introduced to each task using a set of instruction cards.

Instructions for the corresponding task were presented immediately prior to the beginning of each task. The Color task was usually completed prior to the Shape and Pattern task.

Both tasks were identical at the trial level and differed only on the stimuli presented. Participants first saw a sample array of either 4 or 8 items for 500 ms (e.g., colored squares or line-filled shapes) followed by a blank screen for 1667 ms. Then participants saw a test array with a single item that either matched the sample array (no change) or differed from the sample array by one feature (change) until they provided a response. Participants were instructed to respond as quickly as possible by pressing one key when they detected no change and a different key when detected a change. We recorded accuracy and RT for each trial. Following a response, participants saw a fixation cross for 2183 ms.

Stimuli

Color task

In the Color task (Awh et al., 2007) stimuli consisted of 6 distinct colored squares (Figure 1A). Sample arrays consisted of either 4 or 8 (Set Size) colored squares, randomly chosen with replacement (no colored square appeared more than twice in each array). Test arrays consisted of one item that either matched or differed from the sample array item in the same location. Each participant completed a total of 128 trials. Trials were equally divided between each Set Size condition (64 each). Within each Set Size condition, trials were equally divided between no change and change trials (32 each).

Shape and Pattern task

In the Shape and Pattern task (Fukuda et al., 2010), stimuli consisted of black-and-white line drawings of two shapes (ovals and rectangles) that were filled with one of two different line patterns (two parallel lines or two intersecting lines) (see Figure 1B). Sample arrays consisted of

either 4 or 8 items (Set Size). Following the same procedure as Fukuda et al., 2010, stimuli were randomly chosen such that at least one rectangle and one oval were presented. Test arrays consisted of either 1) one item that matched the sample array, in the same location (no change), 2) one item with a change in the overall shape (e.g., oval to rectangle; shape change), *or* 3) one item with a change in the pattern filling the shape (e.g., parallel to intersecting lines; pattern change). Each participant completed a total of 256 trials. Trials were equally divided between each Set Size condition (128 each). Within each Set Size condition, trials were equally divided between the no change and change trials (64 each). Within change trials, half were shape changes and half were pattern changes (32 each). There were 64 no change trials to maintain a 50% probability of a change occurring across all trials. Note that a key difference between the Shape and Pattern task and the Color task is that Shape and Pattern changes were interleaved. This means that participants were required to track two possible change types throughout the Shape and Pattern task, but only one change type throughout the Color task.

Figure 1. Illustration of Change Detection Tasks. A) Color Task. Display is similar to that used in Awh et al. (2007). B) Shape Task. Display is similar to that used in Fukuda et al. (2010). For both tasks, participants saw a sample display of 4 or 8 items (500ms) followed by a blank screen (1667ms). Then they saw one item that was the same item in the same location as in the sample display (no-change) or a different item (e.g., color change, shape change, pattern change) until they responded. Panels within each task illustration display item exemplars.

Analysis Plan

We first conducted a sensitivity analysis using G*Power (Version 3.1.9.6 Faul et al., 2007) to establish the smallest effect size we can detect with the current sample size. Given a total $N = 146$, $\alpha = .05$ and $\beta = .80$, across the 6 groups and numerator $df = 2$ (for interaction terms), we can detect an effect size of approximately $f = .26$, with a critical $F = 3.06$. Thus, we believe we have sufficient power to detect small to medium effects.

For our main analyses, we analyzed two dependent measures of VWM abilities: capacity (K), and performance (P). We calculated VWM capacity (K) according to Cowan (2001), where $K = N_{items} \times (\text{Hit Rate} - \text{False Alarm Rate})$. We also calculated VWM performance (P) according to Lyons et al., (2014), where $P = RT \times (1 + 2 \times \text{Error Rate})$. We calculated P using the median RT for correct trials of each condition because trial-level RT values were positively skewed in some participants. P is interpreted in the same way as RT and is like the inverse efficiency score ($I = RT/\text{Accuracy}$) except that RTs are linearly scaled for P , but non-linearly scaled for *the* inverse efficiency score.

We examined each dependent measure using repeated measures ANOVAs (for color, shape, and pattern conditions separately) with Diagnosis and Age group as between-subject factors and Set Size (4, 8) as a within-subject factor. Note we averaged K scores across Set Size conditions and therefore did not include this factor in these analyses. While our primary goal was to detect age-related difference between the TD and ASD groups, we report all significant main effects and interactions that include Diagnosis or Age group.

Results

Color change detection

Capacity (K)

We first submitted participant's K scores (Cowan, 2001) for Color trials, averaged across Set Size conditions, to a repeated-measures ANOVA with Diagnosis and Age group as between-subject factors. We found only a main effect of Age group, $F_{(2,140)} = 8.308, p < .001, \eta_p^2 = .11$. All other effects and interactions were not significant (*all p's* > .484). Figure 2 shows that VWM capacity, K , increased across Age for both Diagnosis groups.

Figure 2. Age-related increases in visual working memory capacity (K) during color change detection task. Working memory capacity increased with age similarly for both Diagnosis groups. Dashed lines represent the ASD group. Solid lines represent the TD group. Error bars ± 1 SE.

Performance (P)

Color Change. We then submitted participant's *P* scores for Color Change trials to a repeated-measures ANOVA with Diagnosis and Age groups as between-subject factors, and Set Size (4, 8) as a within-subject factor. We found main effects of Age group, $F_{(2,280)} = 10.027, p < 1 \times 10^{-4}, \eta_p^2 = .07$, and Set Size, $F_{(1,280)} = 13.235, p < .001, \eta_p^2 = .05$. All other effects and interactions were not significant (*all p's* > .399). Figure 3 (top) shows that performance on Color Change trials improved with Age for both Diagnosis groups and was generally better for Set Size 4 than Set Size 8.

No Change. We next assessed participant's *P* scores for No Change trials using the same statistical approach as above. We found main effects of Age group, $F_{(2,280)} = 6.626, p < .01, \eta_p^2 = .05$, and Set Size, $F_{(1,280)} = 5.421, p < .05, \eta_p^2 = .02$. All other effects and interactions were not significant (*all p's* > .441). As with the Color Change trials, Figure 3 (bottom) also shows that performance on No Change trials improved with Age group and was generally better for Set Size 4 than Set Size 8.

Figure 3. Age-related improvement in visual working memory performance (P) during color change detection task. The top row depicts color change trials and the bottom row depicts no change trials. The left side depicts Set Size 4 trials and the right side depicts Set Size 8 trials. Working memory performance improved (decreased) with age similarly for both Diagnosis groups. Overall, performance was better for Set Size 4 trials relative to Set Size 8 trials. Dashed lines represent the ASD group. Solid lines represent the TD group. Error bars ± 1 SE.

Shape and pattern change detection

Capacity (*K*)

Shape. We next submitted participant's *K* scores (Cowan, 2001) for Shape trials, averaged across Set Size conditions, to a repeated-measures ANOVA with Diagnosis and Age group as between-subject factors. We found a main effect of Age group, $F_{(2,134)} = 12.94$, $p < .0001$, $\eta_p^2 = .16$, but no other main effects or interactions (*all p's* $> .717$). Figure 4 (left) shows that capacity, *K*, increased across Age similarly for both Diagnosis groups.

Figure 4. Age-related increases in visual working memory capacity (*K*) during shape and pattern change detection task. The left side depicts shape capacity and the right side depicts pattern capacity. Working memory capacity for both shape and patterns increased with age similarly for both Diagnosis groups. Dashed lines represent the ASD group. Solid lines represent the TD group. Error bars ± 1 SE.

Pattern. We then assessed participant's K scores (Cowan, 2001) for Pattern trials, averaged across Set Size conditions, using the same statistical approach as above. We found only a main effect of Age group, $F_{(2,134)} = 8.755, p < .001, \eta_p^2 = .12$. We found no other main effects or interactions (*all p 's* $> .527$). Figure 4 (right) shows that capacity, K , increased across Age similarly for both Diagnosis groups.

Performance (P)

Shape Change. Next, we submitted participant's P scores for Shape trials to a repeated-measures ANOVA with Diagnosis and Age groups as between-subject factors, and Set Size (4, 8) as a within-subject factor. We found a main effect of Age group, $F_{(2,268)} = 5.945, p < .01, \eta_p^2 = .04$, and Set Size, $F_{(1,268)} = 5.427, p < .05, \eta_p^2 = .02$. We found no significant interactions (*all p 's* $> .12$). Figure 5 (top) shows that VWM performance on Shape Change trials improved across Age groups similarly for both Diagnosis groups and was generally better for Set Size 4 relative to Set Size 8 trials.

Pattern Change. We then assessed participant's P scores for Pattern Change trials using the same statistical approach as above. We found only a main effect of Age group, $F_{(2,268)} = 9.321, p < .001, \eta_p^2 = .15$. However, we found no other main effects or interactions (*all p 's* $> .48$). Figure 5 (middle) shows that VWM performance on Pattern Change trials improved across age regardless of Diagnosis and Set Size.

No Change. Finally, we assess participant's P scores for No Change trials using the same statistical approach as above. We found a main effect of Age group, $F_{(2,268)} = 8.030, p < .001, \eta_p^2 = .16$, and Set Size, $F_{(1,268)} = 7.987, p < .01, \eta_p^2 = .03$. However, we found no other main effects or interactions (*all p 's* $> .056$). Figure 5 (bottom) shows that VWM performance on No Change

trials improved across Age groups similarly for both Diagnosis groups and was generally better for Set Size 4 relative to Set Size 8 trials.

Figure 5. Age-related improvement in visual working memory performance (P) during shape and pattern change detection task. The top row depicts shape change trials. The middle row depicts pattern change trials. The bottom row depicts no change trials. The left side depicts Set Size 4 trials and the right side depicts Set Size 8 trials. Working memory performance improved (decreased) with age similarly for both Diagnosis groups. During shape and no change trials performance was better for Set Size 4 trials relative to Set Size 8 trials. Dashed lines represent the ASD group. Solid lines represent the TD group. Error bars ± 1 SE.

Summary

VWM capacity and performance for color, shapes, and patterns improved across age similarly for both the TD and ASD groups. While performance was better on Set Size 4 trials than Set Size 8 trials for Color, Shape, and No Change trials, such an effect was not evident for Pattern Change trials. Note that we reran our analyses using an ANCOVA with age as a continuous variable and found the same pattern of results.

Discussion

We examined VWM for colored squares (e.g., Awh et al., 2007), and simple shapes filled with line patterns (e.g., Fukuda et al., 2010) in children, adolescents, and adults with and without ASD. Overall, VWM capacity and performance improved in a relatively similar manner across age regardless of diagnosis. Moreover, VWM performance was similarly impacted by set size for both the TD and ASD groups. Together these findings suggest that VWM is relatively intact in ASD across development and visual features (i.e., color, shape, pattern). This suggests that neuromaturation may continue typically in the regions thought to underlie VWM tasks, including regions of prefrontal and visual cortices (Serences, 2016). These memory skills may help compensate for some executive function deficits in ASD and support executive function interventions, which may improve social function and developmental outcomes (Vogan et al., 2018).

We predicted that VWM capacity and performance would improve with age for both diagnosis groups, and that differences between these groups would emerge in adulthood (e.g., Luna et al., 2007; O’Hearn et al., 2010). However, we found that both capacity and performance for both colored squares and black-and-white shapes/patterns improved through adolescence and into adulthood for the ASD group, as it did in the TD group. This pattern of late improvement in the ASD group contrasts with developmental studies examining spatial WM (Luna et al., 2007), face and object WM (O’Hearn et al., 2010, 2014), and change detection in complex scenes (O’Hearn et al., 2011). Previous work demonstrating limited spatial WM capacity in children and adults with ASD used spatial WM tasks (e.g., Corsi, Self-ordered pointing) in which success depends on storing and retrieving stimulus locations in the correct sequence (Funabiki & Shiwa, 2018; Joseph et al., 2005). Success in change detection tasks depends on storing stimulus features and location

simultaneously. Another study utilizing a change detection task found that VWM capacity for stimulus *locations* was smaller in children and adolescents with ASD (Jiang et al., 2013), which may reflect deficits in rapid enumeration abilities (O’Hearn et al., 2016). Together with the present study, this suggests that VWM capacity for item locations, but not visual features (i.e., color, shape, pattern), may be smaller in individuals with ASD.

We also predicted that VWM would be differentially influenced by visual feature in ASD. Recent work shows that visual feature processing may influence visual attention abilities in typical children (Lynn et al., 2020). Moreover, some have demonstrated color processing deficits in children and adults with ASD (Franklin et al., 2008, 2010; Maule et al., 2017), shape processing deficits in children with ASD (Grinter et al., 2010), and texture processing deficits but enhanced orientation processing in adolescents and adults with ASD (Bertone et al., 2005). We reasoned that if individuals with ASD prioritize small, local details of objects and scenes then they may more readily commit these features to WM relative to TD individuals that might prioritize more global features such as the spatial relationships between items (e.g., Happé & Frith, 2006). Thus, we expected that the group with ASD would perform better for *pattern* VWM relative to their TD peers, but that the TD group would perform better for color and shape VWM. Overall, VWM capacity and performance for all visual features was similar between ASD and TD groups across development. However, pattern VWM capacity was particularly small in all age and diagnosis groups. In this sense, the pattern filling each item may compete with item shape for storage in WM (Fukuda et al., 2010). Note that, in the Shape and Pattern task, participants were required to track two possible change types, but in the Color task they were required to track only one change. Thus, it may be that performance and capacity differences between the two tasks reflect task demands rather than visual feature, *per se*. Future work should consider task demands as well as which

features compete for encoding and attentional selection (Lynn & Amso, 2021), potentially by blocking trial types by feature (e.g., the color task) rather than interleaving (e.g., shape and pattern task).

The current study is not without its limitations; however, each provides an opportunity for exciting new lines of research. First, VWM capacity estimates tend to be smaller when calculated for set sizes well above the expected VWM limit of ~3-5 items (Fukuda et al., 2015). Despite our finding that capacity estimates did not differ between set size conditions, smaller set sizes (e.g., 2-6) may provide better estimates of VWM capacity, especially when considering typical and atypical development from childhood through adolescence. Second, the current work examines VWM capacity and performance. Emerging work suggests that VWM differences in those with ASD may relate to VWM precision rather than capacity (Hamilton et al., 2018). Thus, future work should examine the typical and atypical development of VWM precision and capacity in tandem. Third, we do not consider how the distribution of visual features across space may influence VWM capacity and performance. Given the known atypical developmental trajectories of spatial WM in ASD (e.g., Luna et al., 2007), it is possible that individuals with ASD may incorrectly bind features and locations. Future work should consider whether performance is affected when the probe feature matches a nearby distractor. Finally, the current study used the ADOS and ADI as tools to diagnose ASD, which was common practice at the time the study began. However, future work should consider a more comprehensive diagnostic assessment, including executive functioning, attention, and sensory-motor functioning to provide nuance for each diagnosis and rule-out other developmental disorders (Kaufman, 2020).

Conclusion

Here, we demonstrate VWM capacity and performance improves from childhood, through adolescence and into adulthood in ASD, as it does in TD. While we found no evidence that VWM capacity and performance depends on visual feature in ASD, these null effects may be influenced by differences in task demand and competition between visual features for attentional selection and updating into VWM. Overall, the present findings suggest that VWM for different visual features may be intact across development in ASD. Future work is needed to examine whether visual feature processing influences other cognitive abilities such as visual attention and cognitive control across both typical and atypical development (Amso & Scerif, 2015; Lynn & Amso, 2021).

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