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RESEARCH ARTICLE

Comparative strengths and challenges on face-to-face and computer-based attention tasks in autistic and neurotypical toddlers

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Abstract

The objectives were to compare patterns of visual attention in toddlers diagnosed with autism spectrum disorder (ASD) as compared to their sex- and age-matched neurotypical (NT) peers. Participants included 23 toddlers with ASD and 19 NT toddlers (mean age: 25.52 versus 25.21 months, respectively) assessed using computerized tasks to measure sustained attention, disengaging attention, and cognitive control, as well as an in-person task to assess joint attention. Toddlers in the ASD group showed increased looking durations on the sustained attention task, as well as reduced frequencies of responding to and initiating joint attention compared to NT peers, but showed no differences on tasks of disengaging attention and cognitive control. The results suggest that toddlers with ASD have attentional strengths that may provide a foundation for building attention, communicative, and ultimately, academic skills.

Lay Summary

We wanted to compare different parts of attention in toddlers diagnosed with autism spectrum disorder (ASD) as compared to their neurotypical (NT) peers. Participants included 23 2-year-old toddlers with ASD and 19 2-year-old NT toddlers assessed using computer-based tasks to measure different parts of visually-based attention, as well as an in-person task to assess social attention. Toddlers in the ASD group showed differences on the computer-based tasks and socially based attention compared to NT peers. The results suggest that toddlers with ASD have attention strengths that can provide a foundation for building attention, communicative, and ultimately, academic skills.

KEYWORDS
attention, autistic disorder, child, computers, joint attention

INTRODUCTION

Autism spectrum disorder (ASD) is a neurodevelopmental condition that is diagnosed in roughly 1 in 44 children (Maenner et al., 2021) and manifests as differences in social communication and the presence of patterns of restricted repetitive interests and/or behavior (American Psychiatric Association, 2013). Atypical attention has been described as one of the fundamental cognitive challenges associated with ASD (Orekhova & Stroganova, 2014). Exercising control over attention is thought of as a "hub" (or foundational) cognitive faculty, required to acquire skills in a range of other domains (Karmiloff-Smith, 1998; Wass et al., 2012). Critically, the ability of the child to respond to environmental events and guide their attention toward information-rich stimuli is essential for learning (Scerif, 2010). This requires several aspects of attention, including selecting stimuli to attend to, sustaining attention toward stimuli in the environment, disengaging from one to attend to a nearby stimulus, and alternating attention between two or more stimuli. As such, early disruptions in any of these aspects may lead to cascade-like patterns of impaired learning across a range of domains (Johnson, 2012; Karmiloff-Smith, 2009).

Impairments in attention have been reported very early in infants who later receive a diagnosis of ASD. For example, Elison et al. (2013) found that infants who are later diagnosed with ASD were slower to disengage attention by 7 months compared to non-diagnosed infants, and Wass et al. (2015) noted differences in micro-temporal eye movement patterns in 6-month-olds who were later diagnosed with ASD. Individual differences in various aspects of attention are correlated with early language development (Kannass & Oakes, 2008; Rose et al., 2009) and learning in academic settings (Razza et al., 2010; Steele et al., 2012; Welsh et al., 2010). One well-studied area of attentional differences in ASD is joint attention, identifying the reduced ability of toddlers with ASD to engage in joint attention behavior (see review by Franchini et al., 2019). Joint attention refers to the one's ability to coordinate their attention between an object/event and a social partner, which consists of making bids to share attention with a social partner (initiating joint attention) and responding to bids from a social partner (responding to joint attention, RJA; Mundy et al., 2009). Interestingly, performance on joint attention, which has largely been viewed as a social construct, influences the development of sustained attention. Yu and Smith (2012) and Suarez-Rivera et al. (2019) found that neurotypical (NT) children showed increased sustained attention (i.e., continual looking) at a target if a caregiver is also attending to said target; indeed, the looking durations were longer when looking at the same target as a caregiver compared to looking at targets without caregiver present. This is important with respect to ASD, for three reasons. Firstly, much of the research on sustained attention has been conducted on NT children. Secondly, joint attention and sustained attention are often studied separately, especially in autistic children. Thirdly, autistic children often display "sticky attention," in that they take longer to look away from an object on which they are visually engaged compared to same-aged NT peers (Bryson et al., 2018; Elison et al., 2013; Elsabbagh et al., 2013; Zwaigenbaum et al., 2005). As such, it may be beneficial to study different facets of attention within the same group of children to assess strengths, challenges, and relationships between the different facets of attention.

The purpose of the present study was measure multiple facets of attention, including selecting stimuli to attend to, sustaining attention toward stimuli in the environment, disengaging from one to attend to a nearby stimulus, and alternating attention between two or more stimuli in NT children and children diagnosed with ASD. Children completed a (non-computerized) joint attention task as well as a series of computer-based attention games that are child friendly, using bright colors and animations to keep children engaged, and target sustained attention (maintaining gaze on a stimulus), disengaging attention (shifting attention from one visual stimulus to another), and cognitive control (alternating attention to learn a new rule; Goodwin et al., 2021). We hypothesized that children in the ASD group would show (1) reduced frequencies of initiating and RJA, (2) reduced ability to maintain attention on an image during a sustained attention task, (3) delays in disengaging attention during a gap-overlap task, and (4) show similar performance on a cognitive control task compared with NT peers. We also predict that there will be relationships between different facets of attention for both the NT and ASD groups.

METHODS

Participants

Participants were two groups of children between 18 and 30 months of age who (1) had a diagnosis of ASD or (2) did not have any developmental diagnoses or for whom there were no such concerns (i.e., neurotypical [NT] children). Children were matched on age (± 2 months) and sex. However, we were not able to complete 1:1 matching (same *n*'s) and our sample size was smaller than we anticipated due to the COVID-19 pandemic. All participants were born between 37- and 42-weeks gestation, with birth weights greater than 2500 grams, and no reports of birth complications. Participants were recruited through a major diagnostic and treatment center in Edmonton, Alberta. The diagnostic status of all children was confirmed using the *Autism Diagnostic Observation Schedule*, 2nd edition (Lord et al., 2012) and the Mullen Scales of Early Learning (Mullen, 1995). The research ethics board at the University of Alberta approved this study and all families gave written informed consent prior to enrollment.

As presented in Table 1, there were no differences between the two groups on any demographic variables measured, including sex assigned at birth, age at assessment, birthweight, gestational age, the mothers' and fathers' education, and the mothers' and fathers' ethnicity/race. We compared mothers and fathers ethnicity/race by white/BIPOC categories and found differences for both the mother ($X^2 = 6.89$, $p = 0.009$) and father ($X^2 = 6.89$, $p = 0.009$), with a higher proportion of white parents in the NT group compared to the ASD group. Children were assessed for signs of ASD, as well as nonverbal cognition, language, and motor development. As shown in Table 2, the ASD group had higher scores (i.e., more ASD characteristics) on the ADOS and PROCESS, and lower scores on the Mullen, as expected. Due to the differences in cognitive ability, the early learning

TABLE 1 Participant Demographics.

Demographic	NT	ASD	Statistic
Sex	10 boys; 9 girls	18 boys; 5 girls	$X^2 = 3.08, p = 0.08$
Age at assessment (months)	25.21 ± 5.31	25.52 ± 4.27	$t = -0.21, p = 0.84$
Range (months)	18.14 to 34.66	18.66 to 31.27	
Birthweight (grams)	3249.38 ± 577.49	3340.36 ± 446.99	$t = -0.48, p = 0.64$
Gestational age (weeks)	39.46 ± 1.21	38.66 ± 1.99	$t = 1.20, p = 0.24$
Mothers' education	5.88% High school	20.00% High school	$X^2 = 3.61, p = 0.46$
	29.41% College	20.00% College	
	0% Partial uni.	5.00% Partial uni.	
	41.18% Uni. undergrad.	45.00% Uni. undergrad.	
	23.53% Graduate training	10.00% Graduate training	
Mothers' ethnicity/race	6.25% First nation	4.76% First nation	
	87.50% Caucasian	47.61% Caucasian	
	0% Black	9.52% Black	
	0% Asian	4.76% Asian	$X^2 = 8.14, p = 0.15$
	0% South Asian	19.05% South Asian	
	6.25% Other	14.29% Other	
	–	–	–
	87.50% Caucasian	47.61% Caucasian	$\chi^2 = 6.89, p = 0.009$
	12.50% BIPOC	52.39% BIPOC	
Fathers' education	22.22% Partial high school	5.26% Partial high school	$\chi^2 = 6.61, p = 0.19$
	5.56% High school	26.32% High school	
	33.33% College	47.37% College	
	22.22% Uni. undergrad.	15.79% Uni. undergrad.	
	16.67% Graduate training	5.26% Graduate training	
Fathers' ethnicity/race	0% First nation	4.76% First nation	
	88.24% Caucasian	47.62% Caucasian	
	0% Black	14.29% Black	
	0% Asian	9.52% Asian	$\chi^2 = 10.50, p = 0.11$
	11.76% South Asian	19.05% South Asian	
	0% Middle Eastern	4.76% Middle Eastern	
	–	–	–
	88.24% Caucasian	47.62% Caucasian	$X^2 = 6.17, p = 0.013$
	11.76% BIPOC	52.38% BIPOC	

Abbreviations: ASD, autism spectrum disorder; BIPOC, Black, Indigenous, and people of color; NT, neurotypical; Uni, University.

composite (ELC) of the Mullen was included as a covariate in the analyses.

Assessment measures

Mullen scales of early learning (Mullen)

The Mullen (Mullen, 1995) is a developmental measure that assesses visual reception, receptive language, expressive language, fine motor and gross motor abilities, yielding an ELC comprising the first four scales, for children aged 0–60 months. We administered all but the gross motor domain for this study.

Autism diagnostic observation schedule—2nd edition (ADOS-2)

The ADOS-2 (Lord et al., 2012) was administered by a research-reliable examiner. The ADOS-2 includes standardized activities and "presses" intended to elicit communication, social interaction, imaginative use of play materials, and repetitive behavior. The Toddler module was administered and social affect (SA), restricted and repetitive behavior (RRB), and total algorithm scores were derived.

Parent-rated observation of communication, emotion, and social skills (PROCESS©). The PROCESS (formerly the Autism Parent Scale for Infants [APSI]; Bryson

TABLE 2 Characteristics of NT and ASD participants.

Demographic	NT	ASD	Statistic
ADOS-2 CSS	Mean (SD)	Mean (SD)	*t (p)*
SA CSS	1.47 (1.02)	8.35 (1.77)	15.71 (<0.001)
RRB CSS	3.84 (2.34)	9.09 (1.20)	9.37 (<0.001)
Total CSS	1.42 (0.96)	9.22 (1.45)	20.11 (<0.001)
Mullen SS	Mean (SD)	Mean (SD)	*t (p)*
Visual Reception	107.42 (16.55)	71.91 (18.56)	6.45 (<0.001)
Fine Motor	101.76 (14.79)	71.35 (16.80)	5.95 (<0.001)
Receptive Lang	109.06 (17.14)	63.43 (17.74)	8.29 (<0.001)
Expressive Lang	107.72 (16.70)	64.00 (11.76)	9.83 (<0.001)
Early Learning Comp	108.94 (17.19)	69.86 (16.41)	6.34 (<0.001)
PROCESS	Mean (SD)	Mean (SD)	*t (p)*
Total score	2.53 (2.67)	25.60 (8.14)	11.91 (<0.001)

Abbreviations: ADOS-2, Autism Diagnostic Observation Schedule, 2nd edition; ASD, autism spectrum disorder; Comp, composite; CSS, calibrated severity score; Mullen, Mullen Scales of Early Learning; NT, neurotypical; PROCESS, Parent-Rated Observation of Communication, Emotion, and Social Skills; RRB, restricted and repetitive behavior; SA, social affect; SD, standard deviation; SS = standard score.

et al., 2006) is a 26-item forced-choice ("yes," "sometimes," and "no") parent-report questionnaire that covers a wide range of behavioral features of ASD in infants aged 6–24 months. More items with responses indicating the presence of ASD-like behavior result in a higher score. The PROCESS has fair to excellent internal consistency (range: 0.77 at 6 months to 0.92 at 24 months), as reported in a sample of children at increased likelihood of ASD (i.e., younger siblings, who received a diagnosis at 36 months) (Sacrey et al., 2018).

Attention measures

Early social communication scales (ESCS)

The Early Social Communication Scales (ESCS; Mundy et al., 1996) is a 20-min structured interaction between child and examiner that is used to assess skills that typically develop between the ages of 8 and 30 months. The ESCS targets three domains: social interaction (e.g., appeals for toy, turn-taking), joint attention (e.g., points, alternating gazes), and behavioral regulation (i.e., child's behaviors when toy ceased to function or was placed out of his/her reach). The ESCS has reliably detected functional impairments in children with autism and developmental delays (Mundy et al., 1990). A video-recorded abridged version of the ESCS was used in this study to measure joint attention (e.g., points, gazes). Specifically, we coded:

1. During toy play and toy spectacle (18 trials):
    a. *Low-level initiating joint attention (IJA)*—(i) child makes *eye contact* with the examiner while manipulating or touching an inactive toy; (ii) child a*lternates eye contact* between active toy and examiner; (iii)
    b. *High-level IJA* – child points at *active toy* with or without eye contact
2. Book (6 trials) and Poster tasks (8 trials):
    a. RJA—child's gaze turns to picture in book or to near (head turn to side) or far (look behind shoulder) posters following examiners point
    b. *Pointing* – child points to pictures in the book or near or far posters *before* the examiner has pointed; pointing occurs with or without eye contact.
3. Bids to caregiver: any unprompted joint attention behavior to caregiver (e.g., eye contact, alternating eye contact, pointing with or without eye contact)

Twenty percent of all ESCS videos were double coded for inter-rater reliability using intraclass correlations (ICC) with a two-way mixed model evaluating absolute agreement on item-level scores. Cicchetti's (1994) guidelines classify ICC scores of less than 0.40 as "poor," between 0.40 and 0.59 as "fair," between 0.60 and 0.74 as "good," and between 0.75 and 1.00 as "excellent." ICC were excellent for each measure, at 0.98 for low-level IJA, 0.93 for high-level IJA, 0.99 for pointing during books and posters, and 0.99 for bids to caregiver.

Eye-tracking tasks

The computer-based attention task uses gaze-contingent animations that rely on eye tracking. Toddlers view the gap-overlap, sustained attention, and cognitive control tasks on a computer screen. Data were collected using a Tobii Pro X3-120 Eye Tracker. During the computer-based tasks, toddlers sat in a high chair or on their parents' laps, with parents wearing infrared glasses to ensure only the toddlers' eyes were being tracked. The attention tasks were presented on a Dell 19-inch monitor, with a screen resolution of 1024 × 768. The tasks were run using MATLAB scripts, written by author SW and previously tested with NT infants (Goodwin et al., 2016).

Gap-overlap task. Trials were presented in blocks of 12. All stimuli were presented at a size of 3 cm × 3 cm (2.86° × 2.86° at 60 cm viewing distance). Each trial started with the onset of a central stimulus (CS), a cartoon image of a spinning ball accompanied by an alerting sound. This pulsed on screen at 3 Hz between 3 and 5 cm (2.86°–4.77°) until fixated by the participant. The CS then rotated at 500° per second for a random 500–700 ms ISI. After the ISI, a 200 ms baseline, gap, or overlap period began, during which the stimuli presented varied according to condition. In the baseline and overlap conditions, the CS remained on screen, and in the gap condition, the CS was removed from the screen. After this 200-ms period had elapsed, the peripheral stimulus (PS) was presented. In the baseline condition, the CS was removed from the screen at the same time as the PS was presented. In the overlap condition, the CS continued to be presented for the rest of the trial. The PS was a cartoon cloud (accompanied by a sound) that appeared on either the left or the right side of the screen, 3 cm (2.86°) from the edge, rotating at 500° per second until fixated by the participant. A reward stimulus was then presented at the location of the PS for 1000 ms. The reward was a randomly chosen cartoon image of a star, a sun, a dog, cat, pig, tiger or tortoise, accompanied by a playful sound. To encourage engagement, the reward stimulus was animated to either spin on the spot, spin and shrink, or to pulse.

Data were analyzed offline. Each trial was inspected automatically to determine trial validity and calculate a saccadic reaction time (SRT) to shift attention from the CS to the PS, relative to PS onset. A trial was valid if the following conditions were met: (1) child gaze fell on the CS; (2) no gaps of missing data longer than 200 ms were present during the CS period (before PS onset); (3) at least one sample of gaze was on the CS within 50 ms of PS onset; (4) no gaps of missing data longer than 100 ms were present during the PS period (between PS onset and reward onset); (5) SRT was longer than 150 ms and shorter than 1200 ms; (6) gaze did not go to the opposite side of the PS; (7) gaze did not enter the PS AOI after engagement with the CS but before PS onset. Trials that failed any of the above criteria were invalidated and removed from further analysis. Mean SRTs were calculated for each condition separately, using only average reaction time in ms for valid baseline, gap, or overlap trials.

Sustained attention. Four still images were presented, in two blocks of two at different stages of the testing protocol. Two of these images were “interesting” (attractive, detailed images of flowers and fish) and two were “boring” (low-detail, monochrome outlines of a diamond and a cross). Trials started once the participant fixated a central target, automatically triggering the picture to appear. Trials ended when the participant looked away from the screen for 1 s or more. Following the end of a trial, a fixation target and brief auditory stimulus (<1 s) were presented. If the participant fixated the target, then the next trial started immediately; if not, a sequence of different fixation targets and auditory attention getters was repeated. Each picture was presented five times, for a maximum of 120 s per trial. Background music was playing during this task. Four variables were extracted:

a. Peak look—the longest look duration in seconds.
b. Minimum look—the shortest look duration in seconds.
c. Mean look—average look duration in seconds.
d. Looking range—peak look duration minus the minimum look duration in seconds.

Cognitive control. Participants were presented with two blocks of 18 trials. Trials began after a central gaze-contingent stimulus was fixated. Two black rectangles (17 cm × 12.5 cm, 16.1 × 11.9° @ 60 cm) were presented 0.5 cm (0.48°) from each edge of the screen and vertically centred. These remained on screen until either (1) one of the rectangles was fixated by the participant, or (2) 2000 ms elapsed. At this point, one of the rectangles was replaced by video of the same dimensions, showing a 2 s clip of the animated children’s TV program Peppa Pig. After the 2 s clip played, the screen was blanked and the next trial began with another gaze-contingent fixation stimulus (based on Wass et al., 2011).

The side of the screen that the video played on was opposite to where the participant chose to fixate in the first trial. For subsequent trials, the participant could make an anticipatory saccade to the blank rectangle on this side, at which point the video would continue playing. The presence and speed of this anticipatory saccade was the main dependent variable. The second trial of each block marked the beginning of the “learning” phase. The side the video clip played on remained fixed through this phase. The learning phase ended after a total of nine trials. After this, the “reversal” phase began, in which the correct side—the side on which the video would now play—was reversed to the opposite side of the screen. On the first trial of the reversal phase the participant was not aware that the reversal had occurred until the video played. All subsequent trials in the reversal phase proceeded as described above, with the exception of the reversed side. We continued to record the presence and speed of an anticipatory saccade to the (new, reversed) correct side. The reversal phase ended following the presentation of nine trials. To continue to the reversal phase, participants had to make at least three sequential saccades to the correct side out of a maximum of nine trials.

Data were analyzed offline. Raw continuous eye-tracking data were segmented into epochs representing each trial for each participant. The first trial of each phase, in which the participant was not yet aware of the correct side, was discarded. For all other trials, offscreen gaze was marked as missing; left- and right-eye data were averaged for samples in which binocular data were available and monocular data for the detected eye were used otherwise. For each participant and for each phase we calculated the number of looks to the correct and incorrect sides during the learning and reversal phases, as well as the proportion of correct anticipatory saccades to the correct side during the learning and reversal phases.

Statistical analyses

Group (ASD, NT) differences for demographic and clinical assessment data were compared using chi-square analyses for categorical data and *t*-tests for continuous data. Levene's test of homogeneity of variances (Levene, 1960) was examined for the continuous tests and results were drawn from "equal variances not assumed" for comparisons that failed the test ($p < 0.05$). Group difference on Mullen scores were significant and large, with the ASD group almost two standard deviations below the mean, so we controlled for developmental level by including the Mullen ELC as a covariate in the attention data analyses. Relations between the various attention tasks and Mullen ELC were explored using Spearman's *rho* correlations.

A multivariate analysis of variance (MANOVA) was run on measures of initiating joint attention, RJA, and caregiver bids on the ESCS with Group (NT, ASD) as the independent variable and the Mullen ELC as the covariate. Data sphericity were not assumed and results were reported using a Pillai's Trace correction (Ates et al., 2019). A series of linear mixed models (LMM) were used to compare Groups on (1) saccadic reaction time (SRT) on the baseline, gap, and overlap conditions on the gap-overlap task, (2) peak look, minimum look, mean look, and looking range durations for the boring and interesting trials on the sustained attention task, and (3) number of looks to the correct and incorrect sides, as well as the proportions of correct anticipatory saccades during the learning and reversal conditions of the cognitive control task with ELC as the covariate in the analyses. LMM was chosen instead of repeated measures ANOVA to include all data that were collected and are considered a nonparametric test. Data loss for each attention task was compared between groups using chi-square analyses.

RESULTS

Joint attention

Initiating joint attention

As shown in Figure 1a, a MANOVA with Mullen ELC as a covariate revealed that the NT group displayed a greater number of lower ($F(1, 41) = 6.45$, $p = 0.015$) but similar numbers of higher level bids ($F(1, 41) = 0.67$, $p = 0.42$) to the examiner compared to the ASD group. The NT group also made more bids to their caregivers ($F(1, 41) = 4.78$, $p = 0.035$) compared to the ASD group.

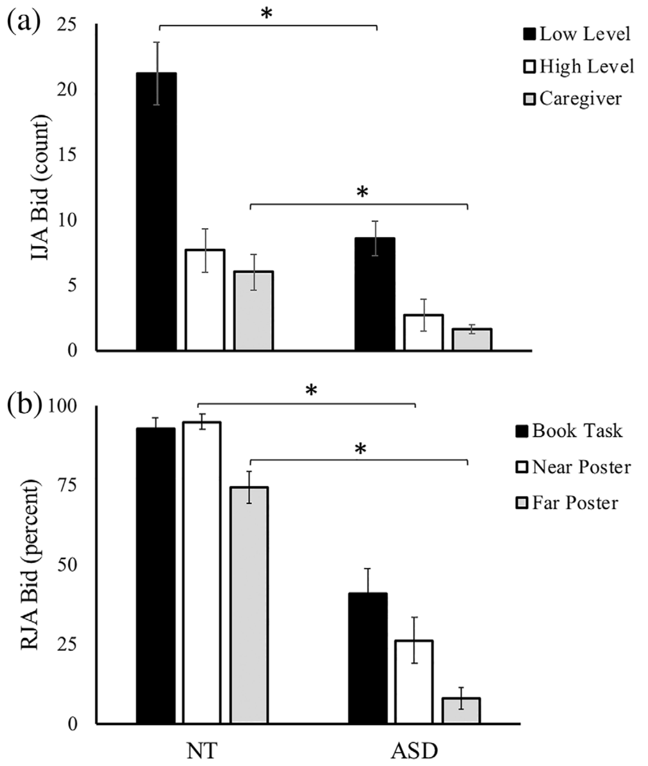

FIGURE 1 Top: Initiating joint attention (IJA) bids, including lower level (eye contact), higher level (pointing), and bids to caregiver. Bottom: Percentages of RJA bids (pointing) during the book task, near posters, and far posters. *Difference between NT and ASD groups.

Responding joint attention

As shown in Figure 1b, the NT and ASD groups did not differ when responding to pointing bids in the book task ($F(1, 41) = 1.55$, $p = 0.22$), but the NT group had a higher percentage of responses to pointing at near ($F(1, 41) = 7.01$, $p = 0.011$) and far ($F(1, 41) = 30.25$, $p < 0.001$) posters.

Gap-overlap task

Linear mixed model analyses with Mullen ELC as covariate resulted in a significant effect for Condition ($F(2, 117) = 51.22$, $p < 0.001$), but no Group ($F(1, 20) = 2.04$, $p = 0.17$) or Group by Condition interaction ($F(2, 117) = 0.42$, $p = 0.66$). Overlap trials (mean = 373.73 ± 82.21 ms) were longer compared to the Baseline (mean = 303.62 ± 55.01 ms) and Gap (mean = 245.01 ± 42.18 ms) trials, which also differed from each other (p's < 0.001).

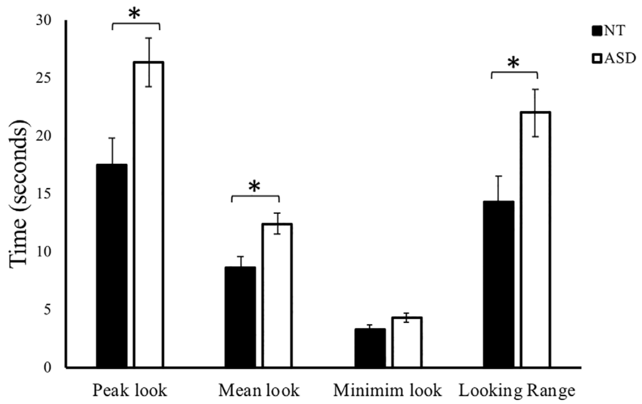

FIGURE 2 Group differences for mean duration of time for the peak look, mean look, minimum look, and looking range duration on the sustained attention task.

Sustained attention

Linear mixed models with Mullen ELC as a covariate for each measure are shown in Figure 2. For peak look, there was a significant Group ($F(1, 80) = 9.10$, $p = 0.003$) and Condition ($F(1, 80) = 15.56$, $p < 0.001$) effect, but no Group x Condition ($F(1,80) = 0.00$, $p = 0.96$) interaction. The NT group had shorter peak look durations compared to the ASD group and peak looks during the boring trials were shorter compared to the interesting trials.

For mean look, there was a significant Group ($F(1, 80) = 10.46$, $p = 0.002$) and Condition ($F(1, 80) = 22.81$, $p < 0.001$) effect, but no Group x Condition ($F(1, 80) = 0.02$, $p = 0.90$) interaction. The NT group had shorter mean look durations compared to the ASD group and mean looks during the boring trials were shorter compared to the interesting trials.

For minimum look, there was a significant Condition ($F(1, 80) = 8.76$, $p = 0.004$) effect, but no Group ($F(1, 80) = 3.32$, $p = 0.07$) or Group x Condition ($F(1, 80) = 0.07$, $p = 0.80$) interaction. Minimum looks during the boring trials were shorter than for the interesting trials.

For range look, there was a significant Group ($F(1, 80) = 7.52$, $p = 0.008$) and Condition ($F(1, 80) = 11.99$, $p < 0.001$) effect, but no Group x Condition ($F(1, 80) = 0.01$, $p = 0.92$) interaction. The NT group had shorter look range durations compared to the ASD group and range look duration during the boring trials were shorter compared to the interesting trials.

Cognitive control

A linear mixed model with Mullen ELC as a covariate for number of looks to correct side during learning and reversal found a Condition ($F(1,67) = 10.35$, $p = 0.002$) effect, but no other significant findings. Overall, there were more correct looks during the learning condition (mean = 7.27; NT range: 5–8 trials; ASD range: 4 to 9 trials) compared to the reversal condition (mean = 6.45; NT range: 4–7 trials; ASD range: 3 to 7 trials). There were no significant Group or Condition effects for number of looks to the incorrect side during the learning or reversal phases, proportion of correct looks during learning or reversal phases, or reaction time for correct anticipatory saccades during learning or reversal.

Associations between attention tasks and Mullen ELC

Spearman *rho* correlations between the attention task variables as well as the Mullen ELC are displayed in supplemental Table 1 and supplemental Table 2 for NT and autistic toddlers, respectively. Briefly, for NT toddlers, the Mullen ELC was not associated with any attention variables. Measures of joint attention were associated with measures on the sustained attention and cognitive control tasks. For autistic toddlers, the Mullen ELC was positively associated initiating higher-level bids, responding to bids during the book task, as well as responding to bids during the near and far poster tasks. Measures of sustained attention were associated with measures on the gap-overlap and cognitive control tasks.

DISCUSSION

We examined group differences across four attentional domains between autistic toddlers and their neurotypical peers. When adjusting for differences in developmental level indexed by the Mullen, there were three main findings. First, as expected autistic toddlers showed reduced levels of initiating and RJA relative to the NT group; they also spent more time looking at boring and interesting still images on the sustained attention task. Second, autistic toddlers performed similarly to their NT peers on the gap-overlap task and measures of cognitive control. Third, NT toddlers only showed associations for joint attention with the cognitive control task and sustained attention task, whereas for autistic toddlers, several associations were found between the Mullen ELC and joint attention, as well as the sustained attention task with the gap-overlap and cognitive control tasks. Taken together, these results suggest that in addition to differences on attention tasks, autistic toddlers have attention strengths that could provide a foundation for building attention, communicative, and ultimately, academic skills.

Autistic toddlers had lower rates of initiating and responding to bids for joint attention. Joint attention is thought to undergird social communication development (Mundy et al., 2009), atypicalities in which are a core feature of ASD (American Psychiatric Association, 2013). The reduced ability of toddlers with ASD to engage in joint attention behavior is well established in the literature (see review by Franchini et al., 2019). A recent meta-analysis found that joint attention ability is moderated by expressive and receptive language in autistic and NT children (Bottema-Beutel, 2016). Bottema-Beutel (2016), suggesting that there is a threshold of joint attention ability beyond which joint attention no longer influences language development. This hypothesis is supported by our data, as there were associations between the Mullen ELC and initiating and RJA for the autistic toddlers, who displayed delays in language acquisition (with expressive and receptive language scores around two standard deviations below the mean) compared to their NT peers, who have expressive and receptive language ability within normal limits and did not show such associations.

In addition to reduced joint attention, autistic toddlers also spent more time looking at still images during the sustained attention task. Autistic toddlers had longer mean looks, maximum looks, and looking duration ranges regardless of whether the stimuli were "boring" (e.g., low-detail, monochrome outlines of a diamond and a cross) of "interesting" (attractive, detailed images of flowers and fish). The basis for the present task is that the child will construct an internal representation through five sequential presentations of each image. After the image is internalized, the infants' attention on the image decreases (Sokolov, 1963). Look durations during sustained attention tasks depend on both the age of the infant and the stimuli presented. Specifically, look durations toward complex, dynamic images show a U-shaped distribution over time, with declining looking durations up to 26 weeks of age, at which point, look durations begin to increase again (Courage et a., 2006). In contrast, look durations toward simple, static images decrease over time (Courage et al., 2006). Looking durations during sustained attention tasks have been associated with information processing (Sigman et al., 1991), childhood intelligence (Kavšek, 2004), and executive function (Cuevas & Bell 20). Children with shorter look durations have shown a bias toward encoding global features before attending to local features of a stimulus, whereas those with longer look durations show no systematic pattern of visual scanning (Colombo, 2001; Colombo et al., 1995). Such scanning patterns have been associated with later recognition memory, such that those with global to local biases show better performance (Colombo et al., 1995). Much of this research on sustained attention has been conducted on NT children, yet children with ASD have been shown to take longer to look away from an object on which they are visually engaged (Landry & Bryson, 2004; Zwaigenbaum et al., 2005), which could impact their performance on sustained attention tasks. In support, a recent paper exploring looking durations to Baby Einstein video clips showed longer looking durations for 5- to 14- month-old infants who were at an increased likelihood for ASD (baby siblings of children diagnosed with ASD) compared to their NT peers (Tonnsen et al., 2018). Although concordant with our findings, an important difference is that our participants were older and were shown static images.

In contrast, autistic toddlers performed similarly to their NT peers on the gap-overlap task. Previous research has indicated that autistic children display "sticky attention," in that they take longer to look away from a central stimulus during overlap trials compared to same-aged NT peers on the gap-overlap task (Bryson et al., 2018; Elison et al., 2013; Elsabbagh et al., 2013; Zwaigenbaum et al., 2005). Other studies, however, have found equivalent performance between autistic and NT participants (Fischer et al., 2014, 2016; Kikuchi et al., 2011; Wilson & Saldaña, 2019). An important difference between these studies is the age of the participants; studies that showed a disengagement delay included participants under two years of age, whereas studies that found no difference between autistic and NT peers were older (at least 2 years), which is in concordance with our findings. "Sticky attention" on the gap-overlap task therefore be a transient phenomenon, which improves during the first few years. Support for this proposition comes from reviews by Colombo and Cheatham (2006) and Sacrey et al. (2014), who note that disengagement takes a developmental U-shaped course during the first three years, with autistic children showing a flatter and prolonged course. It is important to note here, with respect to "sticky attention" that the ASD group had longer looking durations to both static and boring images on the sustained attention task, which could be evidence for getting "stuck," particularly since the group differences seemed to be stronger for "boring" than "interesting" images. The differences between these two tasks is that during the gap-overlap task, a sound cue occurs as targets appear *and* there is another target present that they have to look toward, whereas in the sustained attention task there is no sound or alternate target to look toward (they disengage away from the screen but not toward anything in particular). This may mean that it is easier to disengage in the gap-overlap task, and "sticky attention" behavior only shows up on the sustained attention task.

Our finding of the similar performance on the cognitive flexibility task between autistic and NT toddlers is supported by previous research (Geurts et al., 2009). Autism is associated with a cognitive profile that is often characterized by relative strengths in certain areas (Bury et al., 2020), such as non-verbal tasks, including the Block Design task on the Wechsler measures of intelligence (Meilleur et al., 2015; Mottron et al., 2013), visual search abilities (Kaldy et al., 2016; O'Riordan et al., 2001), and cognitive flexibility (Jiang et al., 2013; this study). As such, tapping into these relative strengths, when present, to exploit the brain's plasticity may promote development in areas of relative weakness for the individual through controlled exposure of attentionally demanding tasks across multiple sessions (Goodwin et al., 2016). One such attention training paradigm, developed by Wass and colleagues, has shown promise in strengthening attention skills in NT children (Wass et al., 2011) and siblings of children with attention deficit hyperactivity disorder (ADHD; Goodwin et al., 2021). Technological methods that rely on gaze may be useful to assess or provide intervention for very young children or children with developmental delays.

The strengths of the current study include the examining different facets of attention in toddlers with confirmed diagnoses of ASD, and comparing their performance to NT toddlers with similar age and sex, while controlling for cognitive ability. However, there are several limitations. Firstly, the sample size was relatively small, reducing power to detect small-moderate differences. Secondly, analyses of the computerized attention data limited the ability to explore attention changes on a trial-by-trial basis, thus allowing only a general interpretation of attentional strengths. Finally, these findings cannot be generalized to children with ASD who have cognitive abilities within normal limits (as measured by the MSEL) and those who may not be diagnosed until later in childhood or adulthood. Nevertheless, the results of this study support the proposition that autistic children display an uneven attentional profile (Bury et al., 2020), showing relative strengths in cognitive flexibility and relative weaknesses in sustained attention and joint attention skills. Future research should include examining whether an attention training intervention improves attention abilities of autistic children, as well as testing potential improvements in other developmental domains.

Clinical implications

The pattern of attentional challenges (sustained attention and joint attention) provides targets for early interventions that can be undergirded by attentional strength (disengaging attention with sound cues and rule learning) in autistic children. Various parent- and teacher-mediated behavioral interventions exist for targeting attention in children of preschool age and beyond (Thompson et al., 2009), yet few such techniques are suited for toddlers and very young preschoolers. One potential approach is computer-based intervention, which uses similar stimuli as in the present study. Using eye tracking as the method, the child interacts with stimuli that respond and adapt depending on where the child looks on the screen (Wass et al., 2011). This method has been found to be feasible in very young typically developing infants (10–14 months) who demonstrated improvements in different aspects of attention following four sessions over 15 days (Wass et al., 2011). As such, computer-based attention intervention may be a viable approach for enhancing attentional development in very young children with early features of ASD. Enhancing attention could have longstanding impacts on a range of domains (Cornish et al., 2007; Karmiloff-Smith, 1998), including language acquisition (Rose et al., 2009), initiating and maintaining social interactions (Mundy et al., 2009), and learning in academic settings (Scerif, 2010; Welsh et al., 2010).

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CONFLICT OF INTEREST STATEMENT

The authors declare no conflicts of interest.

DATA AVAILABILITY STATEMENT

Data are available by reasonable request to the first author.

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