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Brief report: Attention patterns to non-social stimuli and associations with sensory features in autistic children

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A R T I C L E I N F O

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Sensory features

A B S T R A C T

Background: Aberrant attention patterns have been commonly reported in autistic children. However, few studies have examined attention to non-social stimuli varying in salience and complexity using eye-tracking technology, as well as their links to clinical sensory features.
Method: Forty-one children [16 with autism spectrum disorder (ASD), 10 with developmental delay (DD), and 15 neurotypical (NT)] ages 4 to 13 years were included in this cross-sectional study. Children completed a passive-viewing eye-tracking task designed to measure visual attention (e.g., fixation duration and count) to non-social stimuli with sensory qualities involving motion (spinning or non-spinning) and sound. Parents completed a clinical questionnaire about their child's sensory behaviors. Eye-tracking metrics were compared across stimulus conditions and diagnostic groups, and their associations with parent-report sensory features were examined.
Results: Overall children showed longer fixation durations and fewer fixation counts to more complex stimuli (e.g., moving or spinning objects), but such facilitatory effects of stimulus properties tended to be less evident in DD versus ASD or NT groups. More clinical sensory features, especially hyperresponsiveness, were moderately to highly associated with quicker initial fixations and longer fixation durations across stimulus conditions in ASD, but not in DD and NT groups.
Conclusion: The overall attention and initial orientation to non-social stimuli were comparable across autistic children and their non-autistic peers, with some sensory properties such as dynamic motion producing a facilitatory effect (i.e., fewer fixations of longer durations) on attention. However, sensory differences, particularly hyperresponsiveness, might underlie attention patterns as impacted by stimulus properties specifically in autism.

1. Introduction

Eye-tracking provides an objective and quantitative non-invasive methodology for examining attention to and processing of visual stimuli varying in salience and complexity that requires minimal cognitive demands. Despite its extensive applications to the study of

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social attention in autism (Chita-Tegmark, 2016; Frazier et al., 2017; Papagiannopoulou et al., 2014), fewer studies have applied eye-tracking to measure non-social attention. Autistic children are often drawn to salient repetitive visual stimuli, such as a spinning fan (Kirby et al., 2015), and tend to demonstrate strengths in visuospatial abilities, such as better memory for geometric patterns (Hillier et al., 2007) and visual preference for geometric images (Pierce et al., 2011, 2016). Recent imaging studies have reported atypicalities in visual attention networks and neural responses to the properties of salient complex visual stimuli in autism, which were linked to the severity of restrictive and repetitive behaviors (McKinnon et al., 2019; Murphy et al., 2017). In a gap-overlap eye-tracking task that measures differences in the efficiency of orienting towards novel peripheral stimuli, autistic children had significantly slower disengagement from multi-modal complex stimuli compared to non-autistic groups, which was significantly associated with sensory features (Sabatos-DeVito et al., 2016). Autistic children were also reported to show an attentional preference for repetitive movements of stimuli rather than random movements, which was further associated with parent-reported repetitive behaviors (Wang et al., 2018). Together, these results indicate that the *properties* of stimuli (e.g., salience, motion) impact attention and may be associated with autism-related behaviors, including social communication deficits (Amso et al., 2014), repetitive behaviors (Murphy et al., 2017; Wang et al., 2018), sensory features (Sabatos-DeVito et al., 2016), and overall symptom severity (Pierce et al., 2016).

However, the attention patterns to non-social stimuli with various sensory properties and their associations with clinically-defined sensory features, a core feature of autism, remain unclear. Abnormal behavioral responses to stimuli in autistic individuals are noted across modalities (Marco et al., 2011), as well as social and non-social contexts (Baranek et al., 2013), and are included as diagnostic criteria in DSM-5 (American Psychiatric Association, 2013). Sensory features commonly reported in autism include: *hyporesponsiveness* (*HYPO*; diminished or delayed responses to sensory input); *hyperresponsiveness* (*HYPER*; aversive or avoidant responses to sensory input); *sensory interests, repetitions, and seeking behaviors* (*SIRS*; intense or repetitive sensory cravings) (Ausderau, Furlong et al., 2014; Baranek et al., 2006; Ben-Sasson et al., 2009). Previous literature has reported the co-occurrence of sensory features and atypicalities of attention orienting and arousal in autistic populations (Ben-Sasson et al., 2008; Crasta et al., 2020; Liss et al., 2006) as well as in non-autistic populations (Delgado-Lobete et al., 2020; Dellapiazza et al., 2021), which may reflect their common underlying etiology. However, current evidence of the link between sensory and attention behaviors was mostly based on questionnaires or behavioral assessments, thus calling for further investigations with objective measures, such as eye-tracking. Further, as such relationship is not limited to autism, the inclusion of non-autistic controls with and without other developmental conditions could help differentiate the unique impact of autism from more general developmental challenges (e.g., cognitive or motor delay).

In this study, we examined the visuospatial properties of non-social attention in autistic children, children with developmental delay, and neurotypical children using eye-tracking to elucidate the degree to which the sensory properties (e.g., motion and sound) of non-social stimuli impact their attention patterns. In particular, we examined the sensory property of spinning motion on visual attention, given previous parental reports and observational data suggesting autistic children are drawn to visual repetitive motion (e.g., Kirby et al., 2015; Wang et al., 2018). Another aim was to determine the associations between children's non-social attention patterns and parent-reported sensory features in three categories: HYPO, HYPER, and SIRS. We hypothesized that 1) the stimuli with more sensory properties (e.g., motion and sound) would facilitate attention (i.e., fewer fixations and longer fixation duration) in autistic children, and 2) stronger associations between attention patterns and parent-reported sensory features would be observed in autistic children.

2. Method

2.1. Participants

Fifty children [19 with autism spectrum disorder (ASD), 20 with developmental delay (DD), and 11 neurotypical (NT)] ages 4 to 13

Table 1
Participant characteristics.

	ASD (N = 16)	DD (N = 10)	NT (N = 15)	Group Differences		
				F (2, 38)	η^2	Post-hoc†
N (%) of males	13 (81%)	6 (60%)	10 (67%)	–	–	ns
Mean (SD)						
Chronological Age (years)	8.5 (2.57)	10.27 (2.07)	6.98 (2.58)	5.37**	.22	DD>NT**
Mental Age (years)	7.07 (4.41)	3.99 (1.17)	7.87 (4.31)	3.22	.15	NT>DD*
IQ	84.53 (24.01)	54.6 (9.59)	105.85 (12.51)	24.12***	.58	NT>DD***, NT>ASD*, ASD>DD***
SEQ-3.0 HYPO	2.01 (0.53)	1.63 (0.31)	1.22 (0.19)	16.71***	.47	DD>NT**, ASD>NT***
SEQ-3.0 HYPER	2.24 (0.43)	1.93 (0.54)	1.48 (0.25)	13.29***	.41	ASD>NT***
SEQ-3.0 SIRS	2.60 (0.50)	1.90 (0.56)	1.63 (0.34)	17.89***	.49	ASD>NT***, ASD>DD*

SEQ-3.0=Sensory Experiences Questionnaire, Version 3.0; HYPO=hyporesponsiveness, HYPER=hyperresponsiveness, SIRS= sensory interests, repetitions, and seeking behaviors; †Only pairs with significant differences are shown (*$p<.05$, **$p<.01$, ***$p<.001$).

years were recruited as part of a larger study via convenience sampling. Nine participants (3 ASD, 5 NT, and 1 DD) were excluded for a variety of reasons: Not meeting the inclusion criteria as indicated below (N=3), equipment failure (N=2), or behavioral challenges resulting in overall less than 20% fixation time (N=4), which is a criterion based on other previous eye-tracking studies (Harrop et al., 2018, 2019; Tatham et al., 2020). The final sample size included 41 children (16 ASD, 15 NT, and 10 DD).

Children in the ASD group had a clinical diagnosis confirmed by trained researchers using algorithm cut-offs on the Autism Diagnostic-Interview-Revised (ADI-R; Le Couteur et al., 2003) and Autism Diagnostic Observation Schedule-2 (ADOS-2; Lord et al., 2012). No exclusion criteria were set for IQ indexed via the Stanford-Binet Intelligence Scales, 5th Edition [SB5]; Roid, 2003) due to the passive-viewing nature of the eye-tracking task.

Two comparison groups were recruited. Children in the DD group included children with intellectual and developmental disabilities associated with a genetic condition (e.g., Down Syndrome) as well as those with idiopathic DD. Overall IQ scores were >2 two standard deviations (SD) below the mean, or scores across two or more developmental domains were >1.5 SD below the mean. Children in the NT group were confirmed to have no history of developmental issues, special education or intervention. Children in both comparison groups were tested using the ADOS-2 and the Childhood Autism Rating Scale (CARS; Schopler et al., 1988) to ensure they did not have elevated autism symptoms. Sample characteristics for the three groups are reported in Table 1.

2.2. Measures

Child cognitive abilities were tested using the SB5, a standardized measure of verbal and nonverbal IQ. Parents provided demographic information and completed the Sensory Experiences Questionnaire, Version 3.0 (SEQ-3.0; Baranek, 2009), which is a parent-report questionnaire for measuring behavioral responses to sensory experiences in everyday life situations. Caregivers were asked to rate the frequency of their child's sensory behaviors on a 5-point Likert scale ranging from 1 (never/almost never) to 5 (always/almost always). The item responses were averaged for each of the three sensory constructs (i.e., HYPO, HYPER, and SIRS) with higher scores indicating more clinical sensory features. The SEQ-3.0 has been validated for autistic children aged 2-12 years (Ausderau, Sideris et al., 2014) and applied to research that included autistic and non-autistic samples (Sabatos-DeVito et al., 2016; Surgent et al., 2021). Its previous versions have been validated in clinical and general populations with diverse developmental conditions (Baranek et al., 2006; Lee et al., 2022).

2.2.1. Visual attention to non-social stimuli: eye-tracking task

Non-social stimuli were presented on a computer monitor (Width: 47.5 cm × Height: 29.75 cm) with a screen resolution of 1280×1024 pixels. Eye movements were recorded with a Tobii ×120 Eye Tracker sampled at 60 Hz (Tobii Technology, Danderyd, Sweden). Two Logitech speakers were positioned to the left and right of the monitor and set at a standard volume of 60 dB for the auditory components of the task. As shown in Fig. 1, stimuli for the free-viewing task included six novel nonsocial objects: 1) a multicolored globe on a vertical stick that lights up and spins with sound, 2) a white and pink fan with gratings that spin and make a whirring sound, 3) a pinwheel in six colors that makes a light noise when spinning, 4) a yellow, white, and black spiky fish that inflates with an inflating-balloon sound after being compressed, 5) a multi-colored bumble ball that moves while making a vibrating noise, and 6) a lava lamp with pink and blue water bubbles and a bubbling sound. Stimuli were presented on screen within an area of interest measured 235 pixels wide and 228 pixels high (8.3° × 6.3° visual angle) in the center of a black background in one of the three conditions: static visual (object), dynamic visual (object moving but without sound), or dynamic visual+auditory (object moving with sound). Auditory components were added or enhanced for the dynamic images using Adobe Premiere Pro, Version CS4 (Adobe Systems

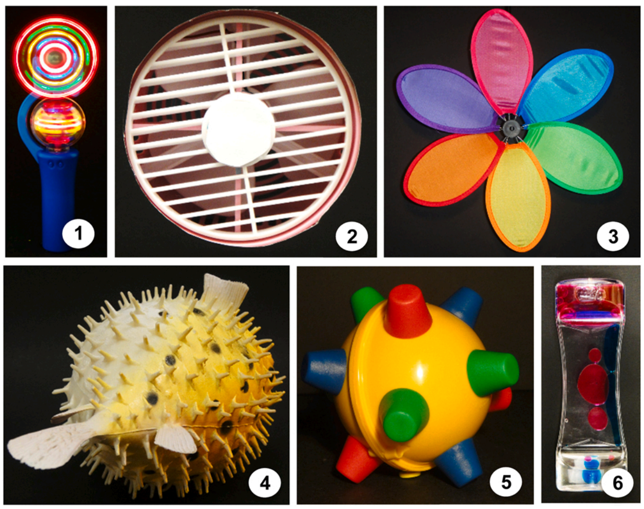

Fig. 1. Non-social stimuli used in eye tracking paradigm with spinning (1-3: globe, fan, and pinwheel) and non-spinning features (4-6: pufferfish, bumble ball, and lava lamp).

Incorporated, San Jose, CA, USA). When presented in the dynamic condition, three of the six objects had a spinning motion (object 1-3), and three had non-spinning motions (object 4-6). Three of Participants sat on a chair placed 60 cm from the computer screen in a quiet dark room with eyes calibrated using a five-point calibration method. They were instructed to "look at the pictures on the computer." The six objects were displayed once in each stimulus condition for 15 seconds in randomized order. A 15-second break occurred between each stimulus, displaying animated characters moving randomly across the screen to sustain engagement. The task ended with a 3-minute animated film.

2.3. Data analysis

The raw gaze data was exported from the Tobii Studio with all available variables and data points included. Tobii's fixation filter (velocity and distance threshold: 35 pixels/window) was applied to raw data for identifying valid fixations. Our analysis focused on five eye-tracking variables of interest: 1) Time to first fixation (i.e., speed of initial orientation to stimuli), 2) First fixation duration (i.e., how long stimuli captured the attention when first displayed), 3) Fixation count (i.e., number of fixations directed towards stimuli), 4) Total fixation duration (i.e., sum duration of all fixations within the 15 s trial the participant attended to the stimuli, and 5) Mean fixation duration (i.e., average length of fixations to a particular stimulus modality). For each stimulus condition, values for each metric were averaged across six objects.

Firstly, diagnostic group and stimulus condition differences were tested for each of the five eye-tracking variables using two-way repeated-measures ANOVA with group×condition interaction. Mental age (MA) derived from the SB5 was included as a covariate to account for its potential effect on attention (Leekam et al., 1998). If significant main and/or interaction effects were observed, post-hoc tests would be performed for examining differences across diagnostic groups and stimulus conditions. The same sets of analyses were then repeated with a specific focus on spinning vs. non-spinning objects for the dynamic visual and dynamic visual+auditory conditions. For all the post-hoc tests, *p*-values were adjusted with the Bonferroni method for multiple comparisons. Finally, we examined the bivariate Spearman correlations between parent-reported sensory features from the SEQ-3.0 and the eye-tracking variables for each stimulus condition. Z tests were performed to determine if these correlations differ by diagnostic group. All statistical analyses were carried out with R 4.1.0 and SPSS 24 (IBM Corp, 2016).

3. Results

3.1. Attention patterns: stimulus condition effects

As shown in Table 2, ANOVA revealed significant stimulus condition effects for first fixation duration [$F(2, 121)=9.58$, $p<.001$, $\eta^2=.145$], total fixation duration [$F(2,121)=4.71$, $p=.011$, $\eta^2=.077$], and mean fixation duration [$F(2,121)=7.15$, $p=.001$, $\eta^2=.112$]. Post-hoc tests indicated that significantly longer first and mean fixation durations were observed for dynamic visual+auditory stimuli than for static stimuli (both $p<.001$). Diagnostic group differences were found in time to first fixation [$F(2,121)=3.58$, $p=.031$, $\eta^2=.060$], fixation count [$F(2,121)=5.27$, $p=.006$, $\eta^2=.085$], and mean fixation duration [$F(2,121)=3.48$, $p=.034$, $\eta^2=.058$]. Specifically, the DD group had more fixation counts than the ASD group across stimulus conditions ($p=.001$).

Despite the non-significant interaction effect, we further examined differences across stimulus conditions for each diagnostic group,

Table 2
Effects of stimulus condition and diagnostic group (controlled for mental age).

Effect	df	F	*p*	η^2	Post-hoc
Time to First Fixation					
DG	2	3.58	.031	.060	ASD>NT*
SC	2	.15	.858	.003	–
DG × SC	4	.60	.663	.021	–
First Fixation Duration					
DG	2	2.61	.078	.044	–
SC	2	9.58	<.001	.145	D>S**, **DA>S*** **
DG × SC	4	.86	.489	.030	–
Fixation Count					
DG	2	5.27	.006	.085	**DD>ASD** **
SC	2	.59	.558	.010	–
DG × SC	4	.69	.597	.024	–
Total Fixation Duration					
DG	2	2.13	.124	.036	–
SC	2	4.71	.011	.077	D>S*, DA>S**
DG × SC	4	.21	.935	.007	–
Mean Fixation Duration					
DG	2	3.48	.034	.058	ASD>DD*, NT>DD*
SC	2	7.15	.001	.112	D>S*, **DA>S*** **
DG × SC	4	.99	.414	.034	–

DG=diagnostic group, SC=stimulus condition, S=static visual, D=dynamic visual, DA=dynamic visual+auditory.
Significant post-hoc test results after correcting for multiple comparisons are bolded (*$p<.05$, **$p<.01$, ***$p<.001$).

which is a recommended practice when significant main effect is found for at least one factor regardless of the statistical significance of interaction effects in a two-way ANOVA (Wei et al., 2012), as well as given our interest in group-specific stimulus condition effects. Table S1 shows that medium to large effects (η^2 >.06; Cohen, 1988) of stimulus conditions were observed in first and mean fixation durations across groups, fixation count for the NT group, and total fixation duration for the ASD group.

3.2. *Attention patterns: spin effects*

As shown in Table 3, spin effects were observed for fixation count [F(1,81)=5.53, p=.021, η^2=.069] and mean fixation duration [F(1,81)=11.02, p<.001, η^2=.128], indicating that overall children made fewer fixations and longer mean fixations to spinning objects as compared to non-spinning objects. Diagnostic group difference was only found in fixation count [F(2,121)=3.33, p=.041, η^2=.082]; the difference between ASD and DD groups became non-significant after correcting for multiple comparisons. No significant interaction effect between diagnostic group and spinning condition was found. However, medium to large spin effects (η^2 >.06) were observed across all eye-tracking variables (except for time to first fixation) for the NT group, and in fixation count and mean fixation duration for the ASD group (see Table S2).

3.3. *Associations between sensory features and attention patterns*

3.3.1. *Zero-order correlations*

No significant associations were observed between the three sensory features and eye-tracking variables across stimulus conditions in the DD and NT groups (see Table S3 for complete results across diagnostic groups). For the ASD group, higher SEQ-3.0 HYPER scores were moderately to highly associated with longer total and mean fixation durations across stimulus conditions (r_s=.49 to .83; Table 4a), as well as longer first fixation durations for static and dynamic stimuli (r_s=.51 and .59, both p<.05). For all conditions, negative associations were found between time to first fixation and HYPER scores, suggesting that autistic children with higher HYPER scores were faster to initially attend to stimuli regardless of condition (r_s=-.46 to -.66; Table 4a). Higher HYPO scores were lowly to moderately associated with longer mean and total fixation durations to some types of stimuli (r_s=.26 to .53; Table 4a). No significant associations were found between eye-tracking variables and SIRS scores, except that longer mean fixation duration for non-spinning stimuli was moderately associated with more SIRS (r_s=.51, p=.042). Fixation count was not correlated with any of the three sensory features. Z tests indicated that many of the associations, especially with HYPER, for the ASD group significantly differed from those for the other diagnostic groups (|z|=1.66 to 2.86, p<.05).

3.3.2. *Partial correlations*

Given the moderate correlation between HYPO and HYPER scores (r=.65, p<.01), we conducted post-hoc partial correlations for the significant zero correlations observed for the ASD group across three eye-tracking variables (i.e., time to first fixation, mean and total fixation durations). As a result, the strength of the associations between the eye-tracking variables and HYPO became negligible when controlling for HYPER (|r|=.01 to .30; Table 4b), while the associations with HYPER remained relatively robust when controlling for HYPO (|r|=.17 to .58; and Fig. 2).

Table 3
Effects of spin and diagnostic group (controlled for mental age).

Effect	df	F	*p*	η^2	Post-hoc
Time to First Fixation					
DG	2	1.42	.248	.036	–
Sp	1	1.09	.301	.014	–
DG × Sp	2	.01	.994	.000	–
First Fixation Duration					
DG	2	2.52	.088	.063	–
Sp	1	3.74	.057	.048	–
DG × Sp	2	1.20	.307	.031	–
Fixation Count					
DG	2	3.33	.041	.082	DD>ASD**
Sp	1	5.53	.021	.069	NSp>Sp*
DG × Sp	2	.56	.572	.015	–
Total Fixation Duration					
DG	2	1.40	.254	.036	–
Sp	1	2.38	.127	.031	–
DG × Sp	2	.83	.441	.022	–
Mean Fixation Duration					
DG	2	1.99	.144	.050	–
Sp	1	11.02	<.001	.128	**Sp>NSp*** **
DG × Sp	2	1.53	.223	.039	–

DG=diagnostic group, Sp=spinning, NSp=non-spinning.
Significant post-hoc test results after correcting for multiple comparisons are bolded (*p<.05, **p<.01, ***p<.001).

Table 4a
Zero-order Spearman correlations (r_s) between SEQ-3 sensory scores and three eye-tracking variables across stimulus conditions for the ASD group.

Stimulus Condition	HYPO			HYPER			SIRS		
	TFF	MFD	TFD	TFF	MFD	TFD	TFF	MFD	TFD
Static Visual	-.43	.26	.28	-.55*	.54*	.62*	-.29	.45	.24
Dynamic Visual	-.53*	.33	.44	-.51*	.54*	.64**	-.22	.36	.25
Dynamic Visual+Auditory	-.37	.27	.53*	-.66**	.49	.72**	-.17	.38	.18
Spinning	-.38	.43	.49	-.46	.54*	.83***	-.12	.35	.23
Non-spinning	-.48	.46	.37	-.56*	.68**	.64**	-.18	.51*	.20

TFF=time to first fixation, MFD=mean fixation duration, TFD=total fixation duration; *$p<.05$, **$p<.01$, ***$p<.001$.

4. Discussion

The current study examined how sensory properties of stimuli (visual and auditory, static and dynamic, spinning and non-spinning) impact attention as measured by eye-tracking, and further, the associations of that attention with parent-reported sensory features among ASD, DD, and NT children. Contrary to our hypothesis that the stimuli with more sensory properties would facilitate more attention in autistic children only, children in all groups looked longer at dynamic visual or dynamic visual+auditory stimuli compared to static visual stimuli, suggesting that stimuli with extra sensory qualities, particularly motion, produced a facilitatory effect on visual attention for all children, irrespective of diagnosis. The addition of sound to the dynamic visual stimuli did not significantly facilitate attention across groups. Our findings were generally consistent with a previous eye-tracking study, where ASD and NT groups showed similar attention patterns in dynamic versus static tasks using social and non-social stimuli (Chevallier et al., 2015). Previous psychophysical evidence also suggested similar visual motion processing patterns across autistic and neurotypical populations (Del Viva et al., 2006; Jones et al., 2011).

Interestingly, we found that attention patterns of the DD group, as compared to NT and ASD controlling for mental age, were generally less affected by the sensory properties of the objects. Specifically, the dynamic motion of the stimuli, whether they were spinning or moving without spinning, did not impact attention in the DD group; in contrast, fewer fixation counts and longer fixation durations (i.e., facilitatory effects of spinning property) were observed in the ASD and NT groups. Our findings suggest that the repetitive spinning motions may capture less interest of children with DD or perhaps that psychomotor delay or slower information processing may be interfering with their performance (Kavšek, 2004; Wilkinson & McIlvane, 2013). The current inclusion of a group of non-autistic children with developmental delay, which was often excluded from eye-tracking studies, might help to fill the empirical gaps on the effects of stimuli properties on visual attention across a broader neurodevelopmental spectrum.

Despite the absence of ASD vs. NT differences in eye-tracking variables across stimulus conditions, we observed significant associations between several eye-tracking variables and clinically-defined sensory features particularly in the ASD group. While the ASD and DD groups did not differ in the level of sensory responsiveness measured by the SEQ-3.0, such association was not observed in the DD group. Although the lack of association may be due to the small sample size of the DD group, it may reflect autism-specific mechanisms underlying attentional and sensory differences (Sabatos-DeVito et al., 2016) that merit further validation with larger samples. The associations between overall longer fixation durations, faster first fixation, and higher levels of hyperresponsiveness that were more evident in the ASD group may be related to reduced inhibitory control and reduced ability to control sustained attention, which were reported to be predicted by sensory processing differences in autistic children (Pastor-Cerezuela et al., 2020). This suggests that sensory hyperresponsiveness (i.e., lower thresholds to stimuli) may act as a protective mechanism for promoting vigilance to novel (and potentially threatening) stimuli and may promote a tendency to over-focus on these stimuli. Another possibility is that high baseline levels of arousal or impairments in disengaging attention may exacerbate sensory hyperresponsive behaviors that manifest clinically. Our finding may be supported by a previous study, where a subgroup characterized by hyperresponsiveness with concomitant overfocused attention was identified in approximately half of their autistic sample (Liss et al., 2006). In contrast, the more directed attention toward dynamic stimuli observed in NT children might be less due to altered sensory thresholds, but rather associated with the increased perceptual load of and/or interests in these stimuli (Lavie, 1995; Vivanti et al., 2016).

The finding that associations between fixation durations and hyporesponsiveness diminish when controlling for hyperresponsiveness, indicates that it is important to consider the co-occurrence of sensory features and their potentially shared mechanisms

Table 4b
Partial correlations with TFF, MFD and TFD across stimulus conditions.

Stimulus Condition	HYPO[a]			HYPER[b]		
	TFF	MFD	TFD	TFF	MFD	TFD
Static Visual	-.27	.19	.26	-.17	.55*	.40
Dynamic Visual	-.30	-.01	.10	-.21	.58*	.43
Dynamic Visual+Auditory	-.10	.20	.24	-.43	.38	.37
Spinning	-.13	.24	.08	-.33	.45	.53*
Non-spinning	-.32	.25	.27	-.18	.48	.27

[a] Controlled for HYPER.
[b] Controlled for HYPO.

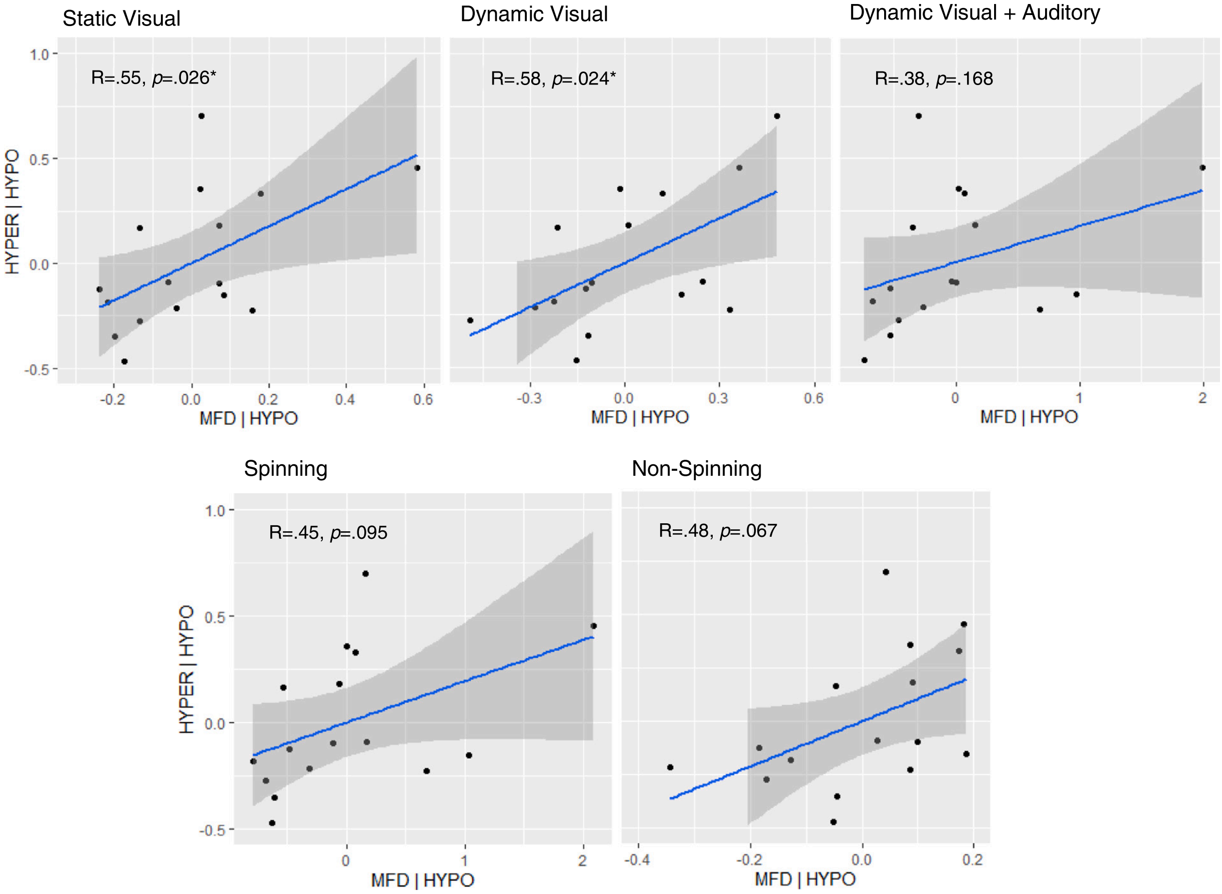

Fig. 2. Scatter plots of partial correlations between mean fixation duration (MFD) and HYPER, controlling for HYPO (ASD group, n=16).

in autism (Ausderau, Furlong et al., 2014; Baranek et al., 2006). A previous eye-tracking study suggested that hyporesponsiveness was associated with impaired attentional disengagement, while hyperresponsiveness was associated with higher levels of disengagement (Sabatos-DeVito et al., 2016). Also, previous neurophysiological evidence has shown that sensory hyperresponsiveness predicted larger event-related potential responses to faces in young autistic individuals (Jones et al., 2018). Thus, the quicker orienting and improved fixation maintenance might reflect the elevated arousal levels in those who tended to be hyperresponsive to certain social or non-social stimuli, despite their potential hyporesponsiveness in other contexts. Future research measuring arousal mechanisms more directly with physiological measures would be helpful to determine the contexts that facilitate or inhibit attention for children with heterogeneous presentations of clinical sensory features.

There are several limitations worthy of discussion. The foremost limitation was that the overall small sample size might underpower our ability to detect meaningful differences. Particularly, the null results involving the DD group might be due to its smaller sample size. Although non-parametric tests were performed with effect sizes reported, future replications with larger samples are necessary for validating the current results. Further, the experimental paradigm focused on visual attention and did not test the auditory modality independent of visual stimuli, which precludes any hypotheses specific to auditory attention. Also, we did not assess children's novelty preference for the stimuli and executive control of attention, which would be important to consider in future research. Longitudinal studies that track changes in the attention and sensory domains across development in high-risk populations are needed to inform whether clinical sensory features are compensatory strategies used to moderate preexisting neural differences that contribute to atypical information processing. The inclusion of physiological measures is also needed in future research to validate mechanistic hypotheses suggested by our behavioral findings.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary material

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.rasd.2022.102035.

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