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Sensory seeking and its influence on sustained attention performance in adult males with Autism Spectrum Condition

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Atypical sensory responses and seeking behaviors constitute the core symptoms of autism spectrum condition (ASC). There are possible links between atypical sensory profiles and attentional challenges in ASC. Due to the paucity of studies in adults, the nature of attentional challenges and their associations with sensory profiles in autistic adults remain elusive. Here, we investigated sustained attention performance and its associations with sensory profiles in 28 autistic adult males and 23 typically developing controls (TDCs). A gradual-onset continuous performance task and the Adolescent/Adult Sensory Profile were employed to assess sustained attention performance and sensory profiles, respectively. Our results revealed that the two groups exhibited comparable sustained attention performance quantified by *d*-prime. A statistically significant negative correlation between *d*-prime and sensory seeking was observed only in the ASC group. Moreover, an interaction effect of group-by-sensory seeking was observed in *d*-prime, suggesting a unique interplay between sensory profiles and attention in autistic individuals. In the ASC group, omission error rate and post-error slowing were statistically significantly associated with difficulties in social communication and interactions. These results contribute to understanding attentional processes in ASC and highlight the potential influence of sensory profiles on cognitive functions in this population.

Autism spectrum condition (ASC) is a neurodevelopmental condition characterized by challenges in social communication and interactions, accompanied by focused interests and behaviors[1]. Unusual sensory responses (i.e., hyper- or hypo-reactivity) to sensory inputs are prevalent and persistent in autistic individuals[2–4]. They are now recognized as core symptoms in the Diagnostic and Statistical Manual of Mental Disorders fifth edition (DSM-5). Sensory profiles are highly heterogeneous in autistic individuals[5–7]and are believed to influence various cognitive functions[7–11], particularly attention. Thus, elucidating the intricate sensory-attention relationships is fundamental for comprehending the overall picture of this disorder.

Both selective and sustained attention are crucial in our daily adaptive behaviors and mental health[12–14]. Among autistic individuals, attentional processes often diverge from those observed in typically developing controls (TDCs). These atypical attentional patterns in autism are characterized by challenges in sustaining attention, shifting focus between stimuli, and filtering out irrelevant stimuli[15–17]. For example, studies have highlighted specific challenges in maintaining attention over extended periods in autistic individuals[18–21]. However, these previous studies have been primarily conducted on autistic children and adolescents. The scarcity of research, especially on sustained attention in autistic adults, emphasizes the need for a more comprehensive investigation into these atypical attentional processes and their practical implications, which are crucial for adaptation to changing environments and meeting daily life demands.

Atypical sensory responses and seeking in autism may result in a cascading effect on attentional processes and social functioning[8,22–24]. These atypical sensory profiles can impair attentional processes, leading to challenges in focusing, maintaining, and shifting attention in response to environmental demands, which can in turn influence social communication and interactions. While previous studies have investigated atypical sensory and attentional processes separately[18,19,25,26], few studies have examined both from the same participants[27,28]. Furthermore, despite the fact that atypical sensory profiles are known to persist in adulthood[4,29], prior studies

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have focused mainly on autistic children and adolescents. These research gaps underscore the critical need for comprehensive studies that explore the interplay between sensory processing and attention in autistic adults.

In this study, our aim was twofold: firstly, to investigate whether autistic adults demonstrate atypical sustained attention performance compared with TDCs, and secondly, to examine whether sensory profiles are associated with sustained attention performance in ASC and TDC groups, respectively. We utilized a gradual-onset continuous performance task (gradCPT)[30]to measure sustained attention ability for the following reasons. First, this task is well-suited for assessing inter-individual differences in sustained attention ability[31–33]. Second, the gradCPT may be more related to sensory profiles than other sustained attention tasks (e.g., AX-CPT), as it involves continuously and subtly changing stimuli. These dynamic stimuli may induce boredom, especially in individuals with high sensory-seeking tendencies. We first assessed whether, compared with the TDC group, the ASC group exhibited atypical sustained attention ability, as quantified by *d*-prime. We then investigated the associations between *d*-prime and sensory profiles measured by the Adolescent/Adult Sensory Profile (AASP)[34] separately for the ASC and TDC groups. These analyses could advance our understanding of ASC and provide insight into therapeutic intervention approaches to this disorder.

Results

Gradual-onset continuous performance task

Twenty-eight adult males with autism and 23 typically developing adult controls participated in this study. Participants completed questionnaires, including AASP, Autism-Spectrum Quotient (AQ), and Social Responsiveness Scale (SRS), and underwent a gradCPT to measure their sustained attention ability. The details of gradCPT are described elsewhere[30,32]. Briefly, the gradCPT used 10 grayscale, circular photographs of mountain scenes and 10 of city scenes, respectively. The images were presented in random order at a ratio of 10% mountain to 90% city, ensuring that no identical image appeared in consecutive trials. Each transition between images was achieved through linear pixel-by-pixel interpolation, lasting 800 ms. All images were shown on an LCD monitor with a 60-Hz refresh rate. Participants were seated in a chair with their heads stabilized by a chinrest, positioned 57 cm from the display. Participants were instructed to press a button for each city scene and to refrain from responding to mountain scenes. Participants were first familiarized with gradCPT by the 30-second practice of gradCPT, followed by an 8-minute run of the gradCPT. According to previous studies[31,32], we calculated several behavioral metrics, including *d*-prime, Coefficient of Variation (CoV), Post-Error Slowing (PES), omission error, and commission error. In this study, we considered each participant's *d*-prime, reflecting the ability to discriminate between city and mountain scenes, as a primary outcome, while other behavioral metrics were considered as the secondary outcomes. The derivations and explanations of primary and secondary outcomes are described in the **Materials and Methods** section.

Demographic data

Table 1 shows the demographic and clinical data of participants in the ASC and TDC groups. Two-tailed, two-sample *t*-tests showed no significant differences in age and full-scale intelligence quotient (IQ) between the two groups ($P > 0.09$). The main effect of the group was observed in the total scores of the AQ and the total and subscale scores of the SRS ($P < 0.001$). For the sensory profile, a significant group effect was observed in all subscales of AASP ($P < 0.05$), except for sensory avoidance ($P = 0.12$). For low registration and sensory sensitivity, the ASC group exhibited higher scores than the TDC group, while they exhibited lower scores in sensory seeking (see Table 1).

Group comparisons on behavioral metrics

Figure 1 presents the results of the behavioral data. Statistical analyses revealed no significant between-group difference in *d*-prime (*t*-value = −1.30, Cohen's $d = -0.35$, $P = 0.20$). For the secondary outcomes, we also found no significant between-group differences (CoV: *t*-value = 1.11, Cohen's $d = 0.30$ $P = 0.27$; PES: *t*-value = −1.71, Cohen's $d = -0.49$, $P = 0.09$; Omission error: *t*-value = 0.43, Cohen's $d = 0.12$, $P = 0.67$; and Commission error: *t*-value = 0.14, Cohen's $d = 0.04$, $P = 0.89$). These results remained consistent after adjusting for age and IQ as nuisance covariates.

As complementary analyses, we conducted the Fligner-Killeen tests to check the homogeneity of group variance. No significant between-group differences were found (all $P > 0.24$), except for CoV ($\chi^2 = 3.96$, $df = 1$, Cliff's $\delta = 0.25$, $P = 0.047$).

Relationships between sensory profiles and behavioral metrics

Figure 2 shows the results of correlational analyses between the sensory profiles and the primary outcome (*d*-prime). In the ASC group, sensory seeking exhibited a significant negative correlation with *d*-prime ($r = -0.49$, $q = 0.03$), while other sensory profiles did not (all $P > 0.20$). In the TDC group, no sensory profile showed significant correlations with *d*-prime (all $P > 0.17$). We conducted a linear hypothesis test to confirm whether sensory seeking was differentially associated with *d*-prime between the two groups (i.e., the interaction effect of group and sensory seeking). The linear hypothesis test confirmed a significant difference ($F(1,47) = 5.09$, Cohen's $f^2 = 0.11$, $P = 0.028$). These results were unchanged after including age and IQ as nuisance covariates. For the secondary outcomes, we did not find statistically significant correlations in both groups (all $P > 0.05$).

Relationships between the clinical symptoms and behavioral metrics in the ASC group

Pearson correlation analyses found no significant correlation between *d*-prime and clinical symptoms (all $P > 0.13$). We found no significant correlations with the AQ and SRS scores (all $P > 0.17$) for the secondary outcomes. PES exhibited a negative correlation with the ADOS communication score ($r = -0.44$, $P = 0.02$), while the omission error positively correlated with the ADOS reciprocal social interaction score ($r = 0.39$, $P = 0.04$).

	TDC (n = 23)		ASC (n = 28)		Statistics		
	Mean	SD	Mean	SD	t-value	Cohen's d	P-value
Age	28.17	6.25	30.93	5.28	−1.67	−0.48	0.10
Full-Scale IQ	107.06	7.04	105.86	12.35	0.44	0.12	0.67
AQ							
Total score	14.83	4.31	33.04	7.25	−11.11	−2.98	< 0.001
SRS							
Total score	38.48	18.03	104.04	35.53	−8.52	−2.26	< 0.001
SCI	32.70	14.63	83.75	28.26	−8.30	−2.21	< 0.001
Awareness	4.30	2.44	11.25	4.55	−6.95	−1.85	< 0.001
Cognition	8.09	3.59	18.71	6.88	−7.08	−1.88	< 0.001
Communication	10.87	7.69	34.04	13.43	−7.72	−2.06	< 0.001
Motor	9.43	3.88	19.75	6.20	−7.24	−1.95	< 0.001
RRB	5.78	4.04	20.29	8.33	−8.12	−2.15	< 0.001
AASP							
Low registration	23.87	5.71	35.36	9.94	−5.17	−1.38	< 0.001
Sensory seeking	39.83	7.53	32.00	8.74	3.43	0.95	< 0.01
Sensory sensitivity	31.96	7.00	37.25	10.83	−2.11	−0.57	0.04
Sensory avoidance	35.96	7.93	40.43	11.94	−1.60	−0.43	0.12
ADOS							
Communication	-	-	3.93	1.84	-	-	-
Reciprocal social interaction	-	-	7.26	1.85	-	-	-
Total score	-	-	11.19	3.34	-	-	-
Creativity	-	-	0.85	0.53	-	-	-
RRB	-	-	0.26	0.53	-	-	-

Table 1. Demographic information. AASP: Adolescent/Adult Sensory Profile, ADOS: Autism Diagnostic Observation Schedule, ASC: Autism Spectrum Condition, AQ: Autism-Spectrum Quotient, IQ: intelligent quotient, SD: standard deviation, SRS: Social Responsiveness Scale, TDC: typically developing control, and RRB: restricted and repetitive behavior.

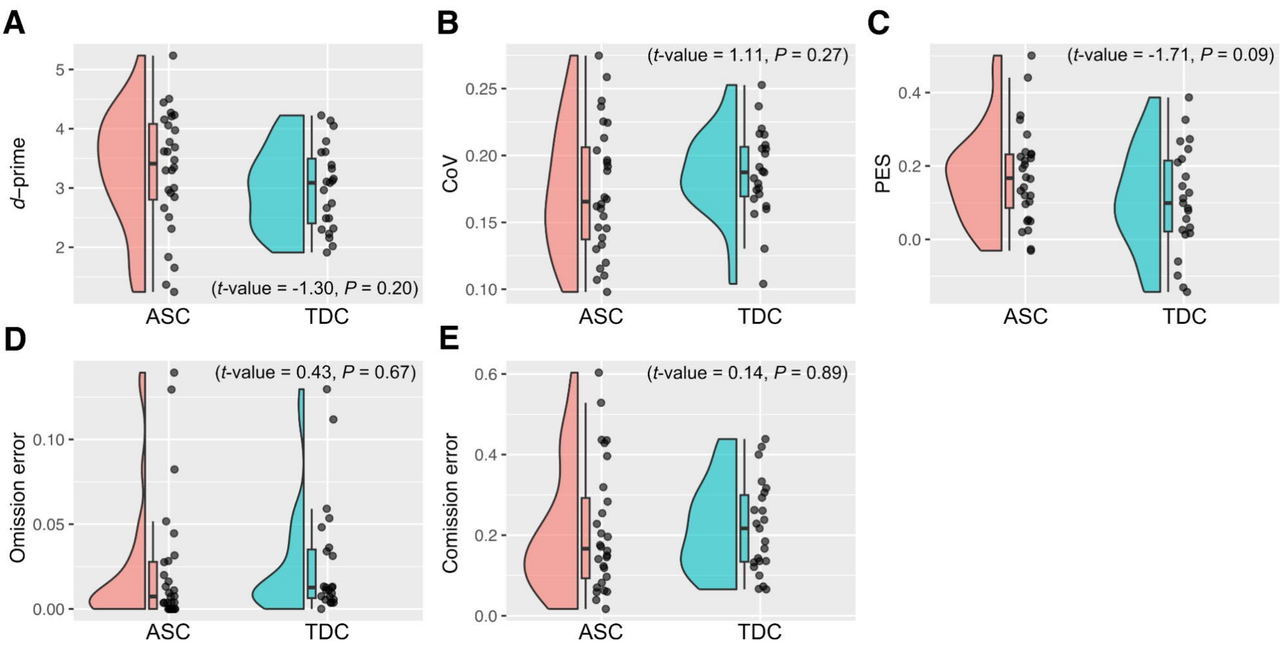

Fig. 1. Raincloud plots of behavioral metrics between the ASC and TDC groups. (**A**) d-prime, (**B**) coefficient of variation (CoV), (**C**) post-error slowing (PES), (**D**) omission error, and (**E**) commission error. ASC: autism spectrum condition and TDC: typically developing control.

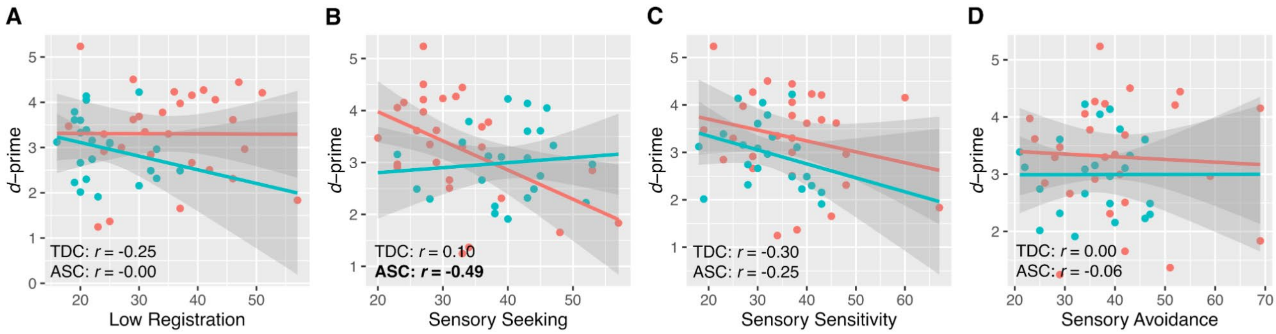

Fig. 2. Relationships between sensory symptoms and *d*-prime performance in the ASC and TDC groups. (**A**) Low registration, (**B**) Sensory seeking, (**C**) Sensory sensitivity, and (**D**) Sensory avoidance. Each subplot represents the linear relationship between sensory profile scores (*x*-axis) and *d*-prime (*y*-axis) with the line of best fit and its confidence interval shaded in grey. Data points are color-coded: red for the autism spectrum condition (ASC) group and blue for the typically developing control (TDC) group.

Discussion

This study investigated whether autistic adults exhibited atypical sustained attention performance compared with TDCs and whether sensory profiles were associated with sustained attention performance measured by the gradCPT separately for the two groups. Our findings indicate comparable sustained attetion performance between the two groups. In the ASC group, sensory seeking was negatively correlated with sustained attention, a pattern absent in the TDC group. This differential relationship, confirmed through linear hypothesis testing, underscores the unique interplay between sensory processing and attentional functioning in ASC. These findings provide new insight into the complicated sensory-attention relationships in ASC and offer new suggestions for understanding and addressing attention-related challenges in this disorder.

Contrary to prior research suggesting sustained attentional challenges in ASC[18–21], our study observed that sustained attention ability in the ASC group was comparable with those in the TDC group. There are three possible explanations for this discrepancy. One possible explanation is the variation in methodological approaches. For example, conventional tasks for measuring sustained attention, such as the Sustained Attention to Response Task, employ a sequence of discrete stimuli, thereby making it challenging to remove the external cues triggered by the abrupt beginnings and endings of these stimuli[35]. In contrast, the gradCPT presents stimuli that evolve subtly over time, eliminating such external cues. This less influence of external, stimulus-driven attention could explain the discrepancies with earlier research. The second possible explanation pertains to the characteristics of the task used in this study. Sustained attention performance is influenced by task demands and task monotony, with higher cognitive load accelerating the depletion of attentional resources and higher monotony fostering attentional drift and mind wandering[36]. The gradCPT, characterized by relatively low cognitive demands and a brief duration of 8 min, may not have imposed sufficient strain to reveal group differences in sustained attention abilities. Another possible explanation is differences in developmental stages. Previous research has predominantly documented attentional challenges in autistic children and adolescents[18,19], while studies focusing on adults have encompassed a broader age spectrum, ranging from 19 to 50 years, and even including older adults[20,21]. This disparity in the ages of participants among various studies may lead to inconsistencies in results. There is evidence suggesting that certain cognitive functions, including attention, may develop toward typical levels as autistic individuals age[37]. Such complex relationships between cognitive functions and developmental stages obscure the understanding of challenges in the cognitive functions of ASC. Future longitudinal studies are necessary to understand the developmental trajectories of attentional profiles in ASC across the lifespan.

Our study observed that sensory seeking was negatively associated with sustained attention performance in the ASC group but not in the TDC group, suggesting a possibility that high levels of sensory seeking may reflect weak top-down attention in ASC. Sensory seeking refers to high neurological thresholds with a tendency to actively seek stimuli[34]. Since the gradCPT is characterized by continuously changing stimuli of weak stimulus intensity and fewer external cues than other sustained attention tasks, subjects must maintain their attention in a top-down manner during the task. Thus, prolonged periods of continuous weak stimulus intensity may cause boredom and difficulty maintaining top-down attention in autistic individuals who exhibit a high propensity for sensory seeking.

The atypical interaction between sensory seeking and attention observed in this study is consistent with previous findings[11]. A potential explanation is that sensory factors, such as sensory sensitivity, may exacerbate the negative impact of sensory seeking on cognitive function. For instance, a previous animal study demonstrated that mice exposed to excessive sensory stimulation during development exhibited increased sensory seeking and impaired cognition[38]. Moreover, several previous studies have reported heightened sensory sensitivity in autistic individuals compared to controls[29,39]. In our additional analyses, we included sensory sensitivity as a covariate in a general linear model with diagnosis, sensory seeking, and their interaction to investigate its potential role in modulating the relationship between sensory seeking and cognitive function (i.e., *d*-prime). The results indicated that while sensory sensitivity was not significantly associated with *d*-prime (*t*-value = −1.31, $P = 0.20$), the interaction between diagnosis and sensory seeking remained statistically significant (*t*-value = −2.16, $P = 0.036$). These findings suggest that the relationship between sensory seeking and cognitive function differs between autistic and typically developing individuals, independent of sensory sensitivity. Atypical sensory sensitivity during development may contribute to increased sensory seeking, but its role in influencing sustained attention is likely limited based on our current data.

The sensory-attention relationship observed in this study may be related to the degree of functional alterations in the cognitive control network in the autistic brain. The cognitive control network comprises several brain regions, such as the inferior frontal cortex (IFC) and anterior cingulate cortex (ACC). This network is associated with top-down attention[40]and has been shown to play a crucial role in situations with perceptual uncertainty[41]or when detecting environmental changes[42]. Furthermore, this region has been associated with sensory seeking behaviors[43,44]. A recent meta-analysis has reported that, compared with the TDC group, the ASC group exhibits altered brain activity in this network (e.g., IFC and ACC) during cognitive control[45]. Our observations, combined with prior neuroimaging findings, may imply that high levels of sensory seeking reflect weak top-down attention through functional alterations of the cognitive control network in the autistic brain. Further studies combining neuroimaging techniques will shed light on the triadic relationship between sensory seeking, brain function, and sustained attention in autistic individuals.

Prior studies have investigated alterations of omission errors or diminished PES in autistic children[46–49]and adults[50,51], but no studies have reported significant associations with the clinical symptoms. Our exploratory analyses found that omission error and PES were significantly correlated with specific ADOS subscales, respectively. PES was negatively correlated with the ADOS communication score, suggesting that greater communication difficulties may impact post-error adjustments; in contrast, omission error was positively correlated with the ADOS reciprocal social interaction score, indicating that social interaction challenges may contribute to attentional lapses or omissions. These differential associations highlight the need for further research to explore the specific mechanisms linking error monitoring processes to distinct clinical features in ASC.

The current results should be interpreted with caution. First, we focused solely on sustained attention because of its implications for academic and social difficulties in ASC[12,52]. Thus, it is unclear whether all attentional processes are comparable between the ASC and TDC groups. Second, this study did not include female participants to increase the biological homogeneity of the sample. Prior research has demonstrated sex differences in attention regardless of diagnosis[53]; this choice limits the applicability of our findings to the broader ASC population. Third, we did not consider the existence of sensory subtypes within the ASC group. Prior studies have demonstrated the presence of sensory subtypes in autistic individuals[5,6,10]. These sensory subtypes may exhibit distinct patterns of challenges in cognitive functions, which may have influenced our findings. Furthermore, we did not investigate the extent to which individual items in sensory seeking contributed to our findings. Therefore, future studies with a larger sample size are necessary to investigate the associations between sensory seeking and cognitive functions in an item-wise manner while considering these sensory subtypes. Fourth, unlike previous studies utilizing the AASP[29,39,54,55], the group differences in sensory avoidance did not reach statistical significance. This is primarily due to the tendency of the TDCs in this study to exhibit high sensory avoidance. However, the recruitment methods employed in this study were consistent with those used in our previous studies[29,54], and there are prior studies in which TDCs demonstrated similar sensory avoidance values[56,57]. In addition, we observed that the ASC group exhibited higher sustained attention ability (*t*-value = −2.09, Cohen's $d = -0.59$, $P = 0.04$) after excluding poor performers (i.e., those more than two standard deviations below the mean), suggesting outliers may influence group comparisons. Thus, the possibility of sampling bias resulting from the modest sample size must be considered. Indeed, a post-hoc power analysis indicates that the sample size in this study is insufficient for detecting small and medium effects. Therefore, future research with a larger sample size is warranted. Fifth, since we recruited TDC and ASC participants using different methods, our findings may be potentially biased due to differences in recruitment procedures. Future research is necessary to recruit participants using the same methods to determine whether our results can be replicated. Sixth, a self-report scale was used to evaluate each individual's sensory profile. Although the AASP has been employed in numerous studies[29,39,54,55], self-report measures are sensitive to individuals' awareness of their issues and differences from most others. Future research may benefit from incorporating objective measures to complement this approach. Sixth, the current study was cross-sectional and focused on autistic adults. Thus, the causality of the sensory-attention relationships and the developmental perspective are lacking. Given the evidence that autistic individuals exhibit atypical brain development compared with TDCs[58], the sensory-attention relationship in ASC may also differ among developmental stages. Seventh, this study employed the JART to estimate IQ scores in the TDC group instead of the WAIS. While the JART has been validated in healthy controls[59]and is widely used in Japanese clinical studies[54,60–62], it is based on reading ability, which introduces the potential for under- or overestimation of certain aspects of intelligence. Future studies could benefit from examining sustained attention while controlling for IQ scores estimated using the WAIS to provide a more comprehensive assessment. Lastly, this study did not assess the symptoms of attention-deficit/hyperactivity disorder (ADHD) in autistic participants. Given that 50–70% of autistic individuals also present with comorbid ADHD[63]and individuals with ADHD show atypical sensory profiles[29,57,64], we cannot rule out the possibility that our findings may be attributable to the ADHD symptoms. Future studies should explore these aspects comprehensively, including multiple behavioral tasks, a broader gender spectrum, a larger sample size from a general population, multiple developmental stages, and individuals with ADHD.

In conclusion, the current study finds comparable sustained attention ability and its unique relationship with sensory seeking in autistic adults. The current findings highlight the importance of sensory symptoms on cognitive functions in autistic adults, and further research investigating the relationship between sensory profiles and cognition in ASC is warranted.

Materials and methods
Ethics statement
All participants provided written informed consent. The institutional review board at Showa University Karasuyama Hospital approved recruitment procedures and experimental protocols, which were conducted in accordance with the Declaration of Helsinki.

Participants
Twenty-eight autistic adult males (30.9 ± 5.3 years old) participated in this study. Autistic participants were recruited from the outpatient unit of Karasuyama Hospital, Showa University, Tokyo, Japan. A clinical team assessed the developmental history, present illness, life history, and family history and then made clinical diagnoses based on the DSM-IV-TR, in line with our previous studies[29,54]. The ADOS Module 4[65,66] was administered to all the autistic participants except for one participant. Twenty-four of the 27 autistic participants met the diagnostic criteria for Autism Spectrum Disorder (ASD) on the ADOS, comprising 16 diagnosed with autism and 8 with ASD. In contrast, three autistic participants did not meet the diagnostic criteria for ASD. Among these, two participants failed to reach the cutoff score on the "Communication" subscale of the ADOS (< 2) but satisfied the cutoff scores for both the "Reciprocal Social Interaction" subscale and the total ADOS score. One participant did not meet the cutoff scores for the "Reciprocal Social Interaction" subscale (< 4) and the total score (< 7) but did meet the cutoff for the "Communication" subscale. Consequently, these three participants were included in the ASC group. Twenty-three typically developing adult controls (TDC; 28.2 ± 6.2 years old) participated in this study. TDCs were recruited via an advertisement that included information such as a brief summary of the research objectives, inclusion criteria (e.g., age ≧ 20 years old), and exclusion criteria (e.g., a history of psychiatric or neurological problems). In this study, we asked controls to indicate if they had a history of psychiatric or neurological problems, severe medical conditions, or a family member with a history of psychiatric problems. None of the TDCs met these criteria.

The IQ scores of autistic participants were evaluated using the Wechsler Adult Intelligence Scale Fourth Edition (WAIS-IV), WAIS-III, or WAIS-Revised. Based on previous studies[54], the IQ scores of control participants were estimated using a Japanese version of the National Adult Reading Test (JART)[59]. Based on the National Adult Reading Test (NART) for English-speaking populations[67], the JART was developed and validated to estimate the IQ scores of normal Japanese individuals by scoring their reading ability of 25 words printed in Kanji (adopted logographic Chinese characters)[59]. Furthermore, it has been widely used in Japanese clinical studies to estimate IQ scores in controls[60,61]. All the participants completed the AASP, which assesses sensory profiles in four domains: low registration, sensory seeking, sensory sensitivity, and sensory avoidance[34]. The four domains of the AASP differ in terms of the ways in which neurological thresholds (i.e., high or low) interact with behavioral responses (i.e., passive or active). Low registration refers to high neurological thresholds and passive behavioral responses, while sensory seeking refers to high neurological thresholds and active behavioral responses. Both sensory sensitivity and sensory avoidance refer to low neurological thresholds, while the former and latter denote passive and active behavioral responses, respectively. Here, a person with 'high neurological thresholds' would take longer to perceive stimuli or be more likely to miss stimuli compared with a person with low neurological thresholds. All the participants completed the AQ[68]and SRS, Second Edition[69] to characterize the autistic traits.

Behavioral analyses for gradual-onset continuous performance task
We calculated behavioral metrics from the gradCPT data of each participant, including d-prime, CoV, PES, omission error, and commission error, according to previous studies[30,31]. The *d*-prime is an index of perceptual sensitivity or accuracy that incorporates both hit and false alarm rates. The *d*-prime is calculated using the following formula:

$d\text{-prime} = Z(\text{hit rate}) - Z(\text{false alarm rate})$,

where $Z()$ represents the inverse cumulative distribution function, which converts hit and false alarm rates into *z*-scores. In this study, a hit is defined as correctly omitting a response to a mountain scene image, while a false alarm refers to an omission error where participants fail to respond to a city scene image. A commission error occurs when participants fail to inhibit a response to a mountain scene image. CoV is a measure used to evaluate trial-to-trial fluctuations in attention. It is calculated based on correct responses to city scene trials and is defined as the standard deviation of reaction times (RTs) divided by the mean RT for each participant. Higher CoV values indicate greater difficulties in maintaining attention. On the other hand, PES measures the extent to which participants delay their responses following an incorrect response, providing an indicator of error monitoring processes.

Statistical analyses
All the statistical analyses were performed using R version 4.2.2. To evaluate the impact of the group on the primary outcome, we used Welch's two-sample *t*-test. The statistical threshold was set to $P < 0.05$.

We performed Pearson correlation analyses to examine whether sensory profiles were associated with sustained attention. Since three out of the four subscales of AASP exhibited significant between-group differences (see Table 1), we performed these analyses in each group. The statistical threshold was set to $P < 0.05$, and we applied a false discovery rate (FDR) correction method[70]. Once statistically significant correlations between sustained attention and sensory profiles were identified in any group, we examined the interaction effect of group and sensory profile on the primary outcome using a linear hypothesis test, which evaluates the statistical contribution of a specific coefficient within a general linear model.

As exploratory analyses, we also performed Pearson correlational analyses to investigate the associations of behavioral metrics with the clinical symptoms (i.e., AQ, SRS, and ADOS scores) in the ASC group. Due to the exploratory nature of these analyses, we set the statistical threshold to $P < 0.05$. The same procedures were applied to the secondary outcomes. We also reported the effect sizes (e.g., Cohen's d) across all the statistical analyses.

Data availability

The datasets generated during and/or analyzed during the current study are available from the corresponding author upon reasonable request.

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Author contributions
T.I. and R.H. designed this study. T.I., R.A., H.O., and M.N. recruited participants, and T.I. collected behavioral and clinical data. T.I. analyzed the data. T.I. wrote the original draft of this manuscript. All the authors discussed the results and revised the manuscript.

Declarations

Competing interests
The authors declare no competing interests.

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