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Reduced preference for smooth over rough surfaces in autism spectrum disorder

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ABSTRACT

Autism spectrum disorder (ASD) is a neurodevelopmental disorder characterized by social communication deficits, repetitive behaviors and restricted interests. Studies have reported atypical sensory responses in individuals with ASD. While atypical affective responses to being touched by others have been documented, preferences for the physical properties of objects in ASD remain poorly understood. Here, we conducted psychophysical experiments to examine whether individuals with ASD show atypical affective responses to object surfaces varying in smoothness. Forty adults with ASD and 40 typically developed (TD) adults provided magnitude estimates of pleasantness or perceived smoothness while their right fingers or forearm were stimulated with raised-dot surfaces of varying interdot spacing. Magnitude estimates of both perceived pleasantness and perceived smoothness decreased with increasing interdot spacing. The decrease in pleasantness was consistently less steep in the ASD group than in the TD group for both forearm and fingers. In contrast, evidence for group differences in smoothness was limited and insufficient to support a reliable group difference. These findings indicate that, compared with TD adults, adults with ASD may show a reduced preference for smoother over rougher surfaces, highlighting an atypical response to textured surfaces, especially with respect to pleasantness.

1. Introduction

Autism spectrum disorder (ASD) is a neurodevelopmental disorder characterized by core symptoms, including impaired social communication and restricted, repetitive behaviors. Altered reactions to sensory input have been noted in ASD since early descriptions of the condition (Kanner, 1943) and may manifest in various forms (Baranek, 1999; Ben-Sasson et al., 2019; Dunn, 1997). While much ASD research has emphasized social deficits (Baron-Cohen, 1995), sensory processing differences have attracted increasing attention because they occur across all ages and levels of severity (Leekam et al., 2007) and can significantly interfere with everyday activities (Suarez, 2012). In recognition of their clinical importance, the DSM-5 (Diagnostic and Statistical Manual of Mental Disorders, 5th edition) formally included sensory abnormalities as part of the diagnostic criteria for ASD (American Psychiatric Association, 2013).

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Interpersonal touch plays a crucial role in cognitive and emotional development during childhood (Field, 2010; Hertenstein, 2002), fosters the formation of social bonds (Matheson & Bernstein, 2000; Suvilehto et al., 2019), and supports psychological as well as physical well-being in adulthood (Cascio et al., 2019; Gallace & Spence, 2010; Jakubiak & Feeney, 2017). Physical contact with a close friend or partner can alleviate both physical and emotional distress (Coan et al., 2006; Kawamichi et al., 2015). However, despite these benefits, there is broad consensus that individuals with ASD exhibit atypical responses to interpersonal touch (Fukuoka et al., 2025; Lee Masson et al., 2019; Mello et al., 2024; Penton et al., 2023; Wada et al., 2023). For instance, adults with ASD report reduced enjoyment of giving, receiving, and observing interpersonal touch in daily life (Lee Masson et al., 2019; Penton et al., 2023). Adults with ASD report lower pleasantness ratings for touch in everyday situations regardless of the social network member involved (Fukuoka et al., 2025). These findings suggest that adults with ASD have a diminished appreciation of interpersonal touch.

One possible explanation for such reduced appreciation is that individuals with ASD show atypical preferences regarding the physical properties of objects. When humans touch an object, they perceive not only its physical attributes but also the emotions associated with those attributes. The ability to identify such physical characteristics is referred to as *discriminative touch*, whereas the associated emotional responses are termed *affective touch* (or emotional touch, McGlone et al., 2007; Schirmer et al., 2023). In discriminative touch, roughness/smoothness, softness/hardness, and warmness/coldness are considered primary perceptual dimensions of surface properties (Hollins et al., 1993; Okamoto et al., 2013). Psychophysical studies in the general population have examined valence (pleasantness and unpleasantness) in relation to physical correlates of temperature (Ackerley et al., 2014; Mower, 1976) and softness (Kitada et al.,. 2021; Pasqualotto et al., 2020). These studies largely found that temperature and softness resembling those of human skin tended to be judged as more pleasant. Such findings support the view that touch preferences in typically developed (TD) individuals are adapted to the physical properties of human skin, consistent with the fundamental role of touch in social bonding (Kitada et al., 2021; Pasqualotto et al., 2020).

Previous work on ASD has examined the effect of physical object properties on perceived tactile pleasantness. Cascio and colleagues measured pleasantness for various textures (brush, plastic mesh, burlap) and found no consistent differences between ASD and TD adults (Cascio et al., 2008, 2012), but reported that fleece was rated as less pleasant by children with ASD than by TD children (Cascio et al., 2016). Because these textures differed along multiple perceptual dimensions, it remains unclear which specific physical attributes influence tactile pleasantness in ASD.

Recently, we conducted a psychophysical study in which TD and ASD adults evaluated the tactile pleasantness of objects with varying compliance, a physical correlate of softness (Makita et al., 2025). We found that pleasantness increased with compliance in both groups, but the rate of increase was attenuated in ASD. Compared with less compliant (hard) stimuli, tactile pleasantness in ASD was reduced at compliance levels similar to those of human body sites. Sensation avoiding scores in the Adult/Adolescent Sensory

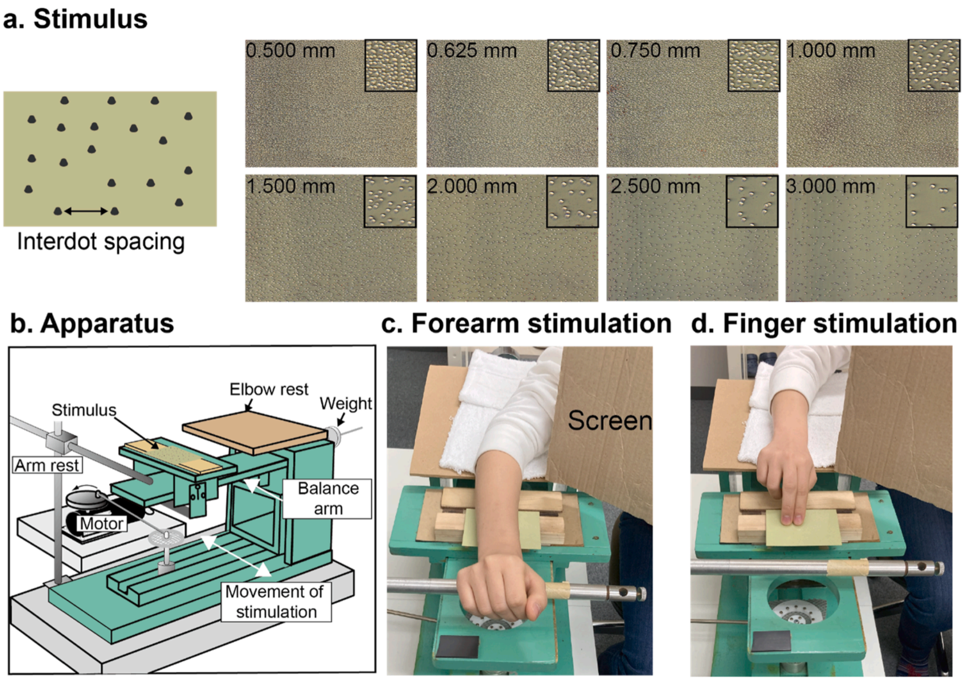

Fig. 1. Experiment setup. a. Stimulus. Eight plates whose surfaces contained transparent truncated cones with varied mean spacings (interdot spacing) were used. Pictures were darkened to highlight the dots. The inset for each plate shows a magnified view of the plate surface. b. Apparatus. The stimulation apparatus was designed to control both force and speed. The stimulus, mounted on the balance arm, was moved sideways. The balance arm moved vertically whenever the counterforce applied to the textured surface by the participant was less than or greater than the target force of 0.49 N. c and d. Forearm and Finger stimulation. In the finger stimulation, the participants used the right index and middle fingers. The participant's view of the stimuli was blocked by a cardboard panel.

Profile (AASP) (Brown & Dunn, 2002) correlated with a coefficient of the functions fitted to pleasantness, suggesting that atypical preferences for body-like tactile properties in ASD may contribute to reduced appreciation of interpersonal touch. This raises the question of whether atypical preferences in ASD extend beyond softness to other perceptual dimensions of surface texture.

One key perceptual dimension is tactile smoothness, typically regarded as the contrasting dimension to roughness. Studies in the general population have examined the physical characteristics underlying tactile roughness perception by manipulating parameters of stimulus surfaces (Connor et al., 1990; Meftah el et al., 2000). These studies consistently show that interelement spacing, defined as the distance between elements on a surface, is the strongest physical determinant of roughness perception by touch. In addition, a previous study in the general population demonstrated that increasing the interdot spacing of two-dimensional (2D) raised-dot patterns monotonically increased the perceived magnitude of both unpleasantness and roughness (Kitada et al., 2012). However, it is unknown whether autistic traits influence pleasantness when touching 2D raised-dot patterns. Research on tactile roughness and smoothness perception in ASD has yielded inconsistent results: studies have reported that ASD and TD groups did not differ in sandpaper discrimination (O'Riordan & Passetti, 2006); that perceived roughness of 2D raised dot patterns was higher in ASD (Haigh et al., 2016); and that ASD and TD groups showed texture-specific differences in pleasantness ratings (Cascio et al., 2012). Many of these studies did not explicitly control applied force, which can affect perceived roughness magnitude (Lederman, 1974, 1983). Thus, it remains an open question whether autistic traits affect the perception of roughness and smoothness for 2D raised-dot patterns when stimulation is applied at a constant force.

In the present study, we psychophysically tested whether adults with ASD differ from TD adults in their pleasantness and smoothness perceptions of 2D raised-dot patterns. We used the same experimental setup as in our previous work (Kitada et al., 2012), in which either the finger or forearm was passively stimulated with 2D raised-dot patterns while applied force and motion speed were matched (Fig. 1). Participants provided magnitude estimates of either the pleasantness of finger/forearm stimulation or the perceived smoothness of the same stimuli. Building on our previous finding (Makita et al., 2025), we hypothesized that the ASD group would show a reduced preference for physically smooth over rough surfaces. Accordingly, we predicted that pleasantness ratings would decrease with increasing interdot spacing in both the ASD and TD groups, but that the rate of decrease would be attenuated in ASD relative to TD (i.e., there would be an interaction between interdot spacing and group). Moreover, we examined whether this attenuation would be evident at interdot spacings close to the spatial structure of the skin, such as the ridge-to-ridge distance of human fingerprints (0.20–0.85 mm; mean approximately 0.40–0.50 mm) (Králík & Novotny, 2003; Moore, 1989). No specific prediction was made for smoothness perception because previous studies on roughness/smoothness discrimination have reported inconsistent findings.

2. Methods

2.1. Participants

Forty adults with a clinical diagnosis of ASD and 40 typically developing (TD) adults participated in the study. All participants self-reported Japanese nationality. This sample size was based on studies that identified group differences in tactile material perception between ASD and TD (Cascio et al., 2016; Haigh et al., 2016; Makita et al., 2025).

Table 1
Participant demographic data and rating scale scores.

	TD n = 40	ASD n = 40	t-value	p-value	Effect size, g
Sex (male/female)	22/18	22/18			
Handedness (right/ambiguous/left)	37/1/2	37/1/2			
Age (yrs)	32.0 ± 7.3	33.8 ± 7.4	0.21	0.83	0.047
FSIQ	109.1 ± 11.7	104.1 ± 11.8	1.90	0.06	-0.42
AQ:					
Total score	19.6 ± 6.8	33.8 ± 5.8	-10.11	< 0.001	2.24
Social skill	4.3 ± 2.8	8.2 ± 2.4	-6.61	< 0.001	1.46
Attention switching	4.4 ± 2.0	7.3 ± 1.6	-7.19	< 0.001	1.59
Attention to detail	3.0 ± 2.0	5.9 ± 2.0	-6.60	< 0.001	1.46
Communication	4.6 ± 2.3	6.9 ± 2.1	-4.60	< 0.001	1.02
Imagination	3.3 ± 2.3	5.6 ± 1.9	-4.94	< 0.001	1.09
AASP:					
Low registration	30.3 ± 7.9	37.6 ± 8.4	-3.974	< 0.001	0.88
Sensation seeking	42.0 ± 7.2	31.8 ± 7.3	6.284	< 0.001	-1.39
Sensory sensitivity	39.0 ± 10.0	46.2 ± 10.0	-3.234	0.002	0.72
Sensation avoiding	38.9 ± 9.9	46.7 ± 10.5	-3.409	0.001	0.76
Touch	32.4 ± 7.1	36.2 ± 6.9	-2.393	0.019	0.53

The age, AQ, and AASP data are mean ± SD. The t-values and p-values are the results of independent-samples t-tests comparing TD and ASD (without family-wise error correction). Handedness was assessed by the Fazio Laterality Inventory (Fazio et al., 2013). FSIQ: Full Scale Intelligence Quotient (Fujita et al., 2011; Wechsler, 1997, 2008); AQ: autism spectrum quotient (Baron-Cohen et al., 2001); AASP: Adolescent/Adult Sensory Profile (Brown & Dunn, 2002), ASD: autism spectrum disorder; TD: typically developed control.

The mean age, sex ratio, and handedness data were matched between the two groups (Table 1). None of the participants reported finger and/or hand injuries. Written informed consent was obtained from each participant after a complete explanation of the study. The study protocol was approved by the Research Ethics Committee of University of Fukui (protocol number: 20220104), and the local ethics committee at the Graduate School of Intercultural Studies, Kobe University (protocol number: 2022–4). All procedures were conducted in accordance with the Declaration of Helsinki and the Ethical Guidelines for Clinical Studies of the Ministry of Health, Labor, and Welfare of Japan. The participants received explanations regarding the purpose and meaning of the study, and written informed consent was obtained from all subjects.

Each participant's cognitive ability was assessed by the Wechsler Adult Intelligence Scale-Third Edition (WAIS-III) or Fourth Edition (WAIS-IV) (Wechsler, 1997; 2008), or by a short form of the WAIS-III (Fujita et al., 2011). A full-scale IQ ≥ 70 was required for inclusion in the study. We also measured the autism-spectrum quotient (AQ) total score (Baron-Cohen et al., 2001) of each participant to confirm the presence/absence of autistic traits, plus the Adult/Adolescent Sensory Profile (AASP) scores (Brown & Dunn, 2002) to measure the participants' sensory processing profile in terms of sensitivity and self-regulation. Scores on the Fazio Laterality Inventory (Fazio et al., 2013) were calculated as the percentage of right-hand use across 10 everyday activities. Following the criteria proposed in the original paper (Fazio et al., 2013), participants with scores ranging from 0 % to 48 % were classified as left-handed; those with scores ranging from 49 % to 59 % were classified as ambiguously handed; and those with scores ranging from 60 % to 100 % were classified as right-handed.

2.2. ASD group

Forty Japanese adults with a clinical diagnosis of ASD (18 females, 22 males; mean age = 33.8 years, standard deviation [SD] = 7.4) were recruited from the University of Fukui Hospital. Two participants were left-handed and one was ambiguously handed, as assessed by the Fazio Laterality Inventory (FLI) (Fazio et al., 2013). ASD was diagnosed according to DSM-5 criteria (American Psychiatric Association, 2013) by an experienced clinician (H.K.) and confirmed using the Diagnostic Interview for Social and Communication Disorders (DISCO) (Wing et al., 2002). In most cases (27/40, 67.5 %), the diagnosis was further confirmed by the Autism Diagnostic Observation Schedule, Second Edition (ADOS-2, Module 4), with a mean ± SD Calibrated Severity Score of 7.6 ± 1.1 (Hus & Lord, 2014), or by the Autism Diagnostic Interview–Revised (ADI-R) (Lord et al., 1994). Some ASD participants reported comorbid psychiatric conditions, including obsessive–compulsive disorder (n = 1), depression (n = 5), sleep–wake disorder (n = 1), bipolar disorder (n = 2), epilepsy (n = 1), and attention-deficit/hyperactivity disorder (ADHD; n = 4). Three ASD participants had multiple comorbid psychiatric conditions (one case of ADHD and epilepsy, and two cases of depression and ADHD).

2.3. TD group

For the control group, we enrolled 40 TD Japanese adults (18 females and 22 males; mean age = 32.37 years, SD = 7.31 years) using a temp agency (Agekke Corp., Tokyo). The agency recruited TD participants for a group whose mean age, sex ratio, and handedness data were matched with those of the ASD group (Table 1). We excluded the participants who reported having been diagnosed with mental, neurological, or developmental disorders during recruitment and the informed consent process.

2.4. Stimuli

We used plates with rigid 2D raised-dot surfaces, as employed in previous studies (Kitada et al., 2012; Klatzky & Lederman, 1999) (Fig. 1a). Rigid surfaces were used because compliant objects can deform, which would interfere with the precise control of interdot spacing. Each surface was approximately 75 mm in length and 100 mm in width, and contained raised dots in the form of truncated cones with a height of 0.52 mm. The base diameter of the dots varied between 0.72 and 0.98 mm as a function of the shoulder angle of the cone sides. The position of each dot was jittered within a defined circular region surrounding the dot's position. Thus, the dots appeared randomly spaced across the plate, yet maintained the original mean interdot spacing (inner edge to inner edge). The stimulus set consisted of 8 plates with mean interdot spacings of 0.500, 0.625, 0.750, 1.00, 1.50, 2.00, 2.50, and 3.00 mm.

2.5. Apparatus

A force-controlled device modeled after a classical balancing scale was used in this study (Fig. 1a), as in previous studies (Kitada et al., 2012; Lederman, 1974, 1983). The stimulus, one of the textured plates described above, was held in place by magnets on a platform attached to the front end of the balance arm. To touch the stimulus surface, participants used their right index and middle fingers in the finger conditions and their ventral forearm in the forearm condition. In both conditions, participants were instructed to keep the balance arm stable throughout the trial. To maintain constant force on the skin from the stimuli, participants were instructed to hold the balance arm steady at a certain height throughout the trial. In doing so, a well-defined force was applied to the participant's forearm to counterbalance the weight on the rear arm of the device. The applied force was set at 0.49 N to ensure comparability with a previous study on pleasantness (Löken et al., 2009).

The stimuli were moved back and forth beneath the skin by driving the balance arm side to side by the rotating base to which it was attached. The rotating base was connected to a motor via a linear metal rod. The horizontal movement range was approximately 5.5 cm, with a velocity of about 3.7 cm/s; these parameters were similar to those used by Löken et al. (2009). A cardboard screen was placed between the device and the participant to prevent visual observation of the stimuli being touched. Unlike Kitada et al. (2012), we did not use background masking noise in this study, as such noise can be uncomfortable for individuals with ASD. Instead, we confirmed that the stimulation itself produced negligible sound. Moreover, previous work has shown that the psychophysical function for tactile roughness perception is highly similar regardless of the presence of auditory cues (Lederman & Klatzky, 2004).

2.6. Experimental design and procedures

We adopted an experimental design with two within-subject variables—namely, interdot spacing (eight levels) and body sites (fingers and forearm)—and two between-subject variables, group (ASD and TD) and biological sex (male and female). We included sex as a factor based on previous studies (Kumazaki et al., 2015; Lai et al., 2011). There were four experimental sessions: two for finger stimulation and two for forearm stimulation. The order of body site stimulation was counterbalanced across participants, such that some completed the two finger sessions first and others the two forearm sessions first. To prevent participants from conflating smoothness with pleasantness, the pleasantness session was always conducted before the smoothness session (Makita et al., 2025).

In each session, stimuli were presented in a pseudo-random order, determined separately for each of the four repetitions per participant. The first repetition served as practice and was not recorded (Kitada et al., 2012, 2021; Pasqualotto et al., 2020). An absolute magnitude estimation method was used to assess either the pleasantness or smoothness of each surface (Zwislocki & Goodman, 1980). Under the pleasantness task, participants selected the number that best matched their perceived pleasantness for each stimulus; in the smoothness task, they selected the number that best matched the perceived smoothness. Participants were told they could use any number (decimal, fraction, or integer) greater than zero. Each trial began when the experimenter gently raised the stimulus platform until participants could counterbalance it with their fingers or forearm. Before the main experiment, participants were trained to keep the balance arm steady and level (in the finger condition, this involved holding their two fingers together).

After the main experiment, participants completed a supplementary experiment in which they evaluated the perceived pleasantness of each surface using a bounded 0–10 scale (0 = very unpleasant, 10 = very pleasant). Each participant was stimulated with each surface once, with the plates presented in ascending order of interdot spacing. The entire experiment lasted approximately 90 min, with a short break allowed after completing two sessions of the main experiment.

2.7. Analyses

To analyze the participants' magnitude estimate scores, we used a conventional procedure employed in the previous studies (Kitada et al., 2012; Lawrence et al., 2007; Pasqualotto et al., 2020). The data were averaged across three repetitions and normalized within each perceptual condition to eliminate possible biases due to the participants' use of different number ranges. We performed the normalization procedure by dividing each data point by the participant's mean and then multiplying that value by the grand mean for each instruction. Finally, to provide a more normal distribution of the magnitude estimates (Gescheider, 1997), the scores were logarithmically transformed (base 10) and used for the data analyses.

We examined the group differences in the pleasantness and smoothness data independently because these are qualitatively different perceptual dimensions. For the comparison of the magnitude estimates between the two groups, we conducted a four-way mixed analysis of variance (ANOVA) (8 interdot spacing × 2 groups × 2 body sites × 2 sexes) and post-hoc independent *t*-tests with Bonferroni correction. The Greenhouse–Geisser correction was applied to adjust for the lack of sphericity in a repeated-measures ANOVA. We then fitted a linear function to the data as a function of interdot spacing, following a previous study using the same stimuli and procedures (Kitada et al., 2012). Model comparisons using the corrected Akaike Information Criterion (AICc) indicated that the linear model was favored for the forearm data, whereas a quadratic model showed slightly better support for the fingertip data (maximum ΔAICc = 3.2). Given this modest difference in AICc and to maintain consistency across body sites and with previous work,

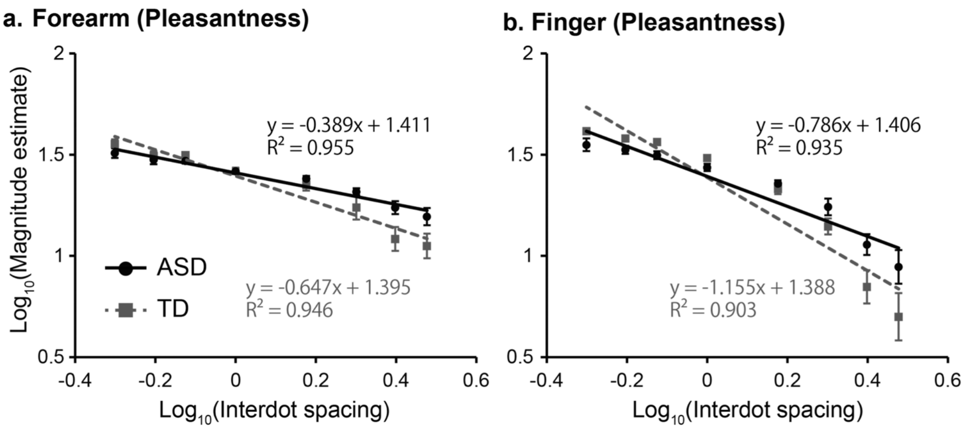

Fig. 2. Magnitude estimates of pleasantness. Mean $\log_{10}$ normalized magnitude estimates of pleasantness as a function of interdot spacing. Linear functions fitted to the pleasantness data are shown in black for the ASD group and gray for the TD group. Each data point represents the mean ± SEM of 40 participants. A significant interaction between group and interdot spacing was observed (p = 0.037, see the main text).

we adopted the linear model for the analyses.

3. Results

3.1. Questionnaires (AQ and AASP)

Table 1 summarizes demographic information and FSIQ, AQ, and AASP scores. The ASD group showed significantly higher AQ total scores than the TD group [$t_{78} = 10.11$, $p < 0.001$, Hedges' $g = 2.24$]. AASP scores were also significantly higher in the ASD group for low registration, sensory sensitivity, and sensation avoiding, whereas sensation seeking was significantly higher in the TD group (all p values < 0.001; Table 1). The AASP touch rating was significantly greater in the ASD group [$t_{78} = 2.39$, $p = 0.019$, $g = 0.53$]. Collectively, these results confirmed an atypical sensory profile, including touch, in the ASD group. No significant difference in FSIQ was observed between the ASD and TD groups ($p = 0.06$).

3.2. Magnitude estimates of pleasantness

We first examined the mean values of the magnitude estimates as a function of interdot spacing. The obtained magnitude estimates were normalized and transformed into logarithms (base 10) (Lawrence et al., 2007; Zwislocki & Goodman, 1980). Fig. 2a,b depicts the patterns of the mean magnitude estimates for pleasantness for the forearm and fingers. The four-way ANOVA (8 interdot spacing values × 2 body sites × 2 groups × 2 sexes) on pleasantness estimates showed significant main effects of body sites ($F_{1, 76} = 29.39$, $p < 0.001$, $\eta_p^2 = 0.28$) and interdot spacing ($F_{1.25, 95.12} = 83.98$, $p < 0.001$, $\eta_p^2 = 0.53$). The same analysis also revealed significant interactions between group and interdot spacing ($F_{1.25, 95.12} = 4.10$, $p = 0.037$, $\eta_p^2 = 0.051$) and between body site and interdot spacing ($F_{3.03, 230.41} = 31.07$, $p < 0.001$, $\eta_p^2 = 0.29$). No other significant effects were observed (all p values > 0.06).

We conducted post-hoc independent *t*-tests for each stimulus (with Bonferroni correction over 8 samples), collapsing sex and body site because they did not significantly interact with group. This analysis revealed significantly greater magnitude estimates in the TD group than in the ASD group at 0.75 mm of interdot spacing (-0.125 on a base-10 logarithmic scale) [$t_{78} = 2.84$, $p_{bonf} = 0.048$, $g = 0.63$] (see Supplementary Table 1 for details).

A supplementary experiment using a bounded 0–10 scale (0 = very unpleasant, 10 = very pleasant) confirmed this result (Supplementary Fig. 1). Specifically, the same four-way ANOVA revealed a significant interaction between group and interdot spacing ($F_{1.61, 122.14} = 5.17$, $p = 0.011$, $\eta_p^2 = 0.064$). Ratings were significantly higher in the TD group than the ASD group at 0.5, 0.625 and 0.75 mm (all p values < 0.05; Bonferroni-corrected; see Supplementary Materials for details).

3.3. Magnitude estimates of smoothness

Fig. 3 shows the magnitude estimates of perceived smoothness. The four-way ANOVA (8 interdot spacing values × 2 body sites × 2 groups × 2 sexes) on smoothness estimates showed significant main effects of body site ($F_{1, 76} = 49.31$, $p < 0.001$, $\eta_p^2 = 0.39$) and interdot spacing ($F_{1.22, 92.73} = 180.15$, $p < 0.001$, $\eta_p^2 = 0.70$). In addition, a significant interaction was found between body site and interdot spacing ($F_{2.63, 199.73} = 44.41$, $p < 0.001$, $\eta_p^2 = 0.37$). The interaction between group and interdot spacing showed a trend for significance ($F_{1.22, 92.73} = 3.44$, $p = 0.059$, $\eta_p^2 = 0.043$). No other significant effects were observed (all p values > 0.1) (see Supplementary Table 2 for details).

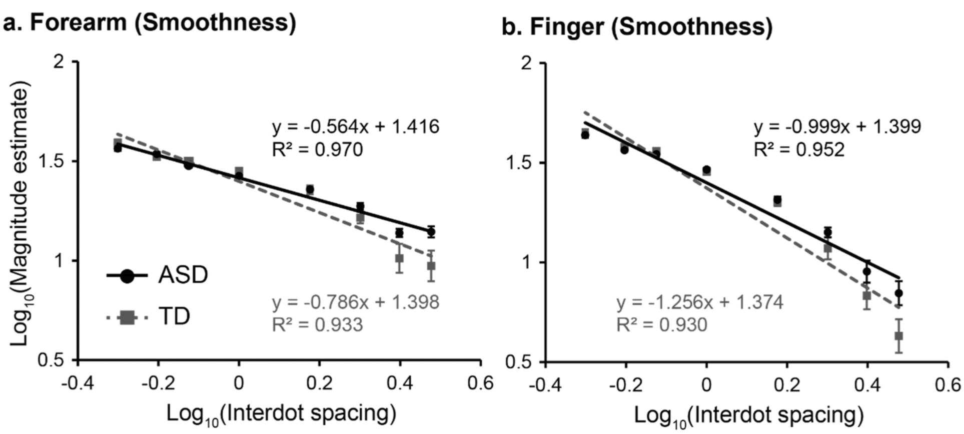

Fig. 3. Magnitude estimates of smoothness. Mean $\log_{10}$ normalized magnitude estimates of smoothness as a function of interdot spacing. Linear functions fitted to the data are shown for in black for ASD and gray for TD. Each data point represents the mean ± SEM of 40 participants. No significant interactions were observed.

3.4. Slope analyses

To examine the interaction effects between group and interdot spacing, we fitted linear functions to each participant's data and compared the slopes between TD and ASD adults. Differences in slope would indicate that the sensitivity of perceived magnitude to changes in interdot spacing varied between groups.

Fig. 4 shows the slopes of the fitted linear functions. The mean coefficients of determination (R^2) ranged from 0.73 to 0.92, indicating that linear trends accounted for most of the variance (Supplementary Table 3). The four-way ANOVA (2 instructions × 2 body sites × 2 groups × 2 sexes) revealed a significant main effect of group, with the TD group showing more negative slope values than the ASD group ($F_{1, 76} = 4.44$, $p = 0.039$, $\eta_p^2 = 0.055$). Significant main effects were also found for instruction, with pleasantness instruction producing significantly less negative slope values than smoothness instruction ($F_{1, 76} = 12.79$, $p < 0.001$, $\eta_p^2 = 0.144$), and for body site, with the fingers showing significantly more negative slope values than the forearm ($F_{1, 76} = 117.70$, $p < 0.001$, $\eta_p^2 = 0.608$). No other main effects or interactions were significant (all p values > 0.1).

To further assess the robustness of the group difference, we conducted a series of supplementary analyses on slope values. These analyses showed that the group difference in slope values remained significant after controlling for age and FSIQ, and that medication use for comorbid conditions did not show significant effects on the ASD data. In addition, no significant correlations were observed between slope values and AQ or AASP scores (see Supplementary Materials).

4. Discussion

The main findings of the present study are twofold. First, although pleasantness decreased monotonically with increasing interdot spacing in both groups, there was a significant interaction between group and interdot spacing. Slope analyses revealed that the decrease was greater in TD than in ASD participants. Second, increasing interdot spacing also reduced perceived smoothness in both groups; however, the group difference was less pronounced than for pleasantness. The interaction between group and interdot spacing was only marginally significant, although slope analyses indicated that the magnitude of the group difference was comparable to that observed for pleasantness.

The present study showed that, although both groups exhibited negative slopes, the slopes derived from linear functions describing pleasantness as a function of interdot spacing were less negative in ASD than in TD participants. Because slope values reflect the relative change in pleasantness between physically smoother and rougher surfaces, this pattern indicates a relatively reduced preference in the ASD group for surfaces with lower interdot spacing (i.e., physically smoother surfaces) compared with those with larger interdot spacing. We used a device previously employed to passively stimulate the skin while controlling both the speed of motion and the force applied to the stimulated area (Kitada et al., 2012). Controlling applied force is critical because perceived roughness magnitude is influenced by force (Lederman, 1974), whereas speed can affect pleasantness (Kitada et al., 2012). It is therefore unlikely that group differences in these parameters account for the observed effects. Previous studies have compared the effects of different textures on pleasantness in ASD and TD groups (Cascio et al., 2008, 2012, 2016), but the extent to which physical determinants of smoothness or roughness influence pleasantness in ASD has remained unclear. Our earlier work demonstrated an effect of interdot spacing on pleasantness in the general population only (Kitada et al., 2012). In contrast, the present study demonstrates that the interdot spacing of 2D raised-dot patterns on a rigid surface affects pleasantness in both adults with ASD and adults with TD, albeit in a differential manner.

Our results align with a previous study showing atypical patterns of pleasantness for compliant objects. Specifically, Makita et al. (2025) showed that, when touching different types of urethane rubber, pleasantness increased with compliance, but this increase was significantly smaller in individuals with ASD than those with TD. The group difference was observed at compliance levels resembling those of human body sites. In the present study, significant group differences in magnitude estimates were observed at an interdot

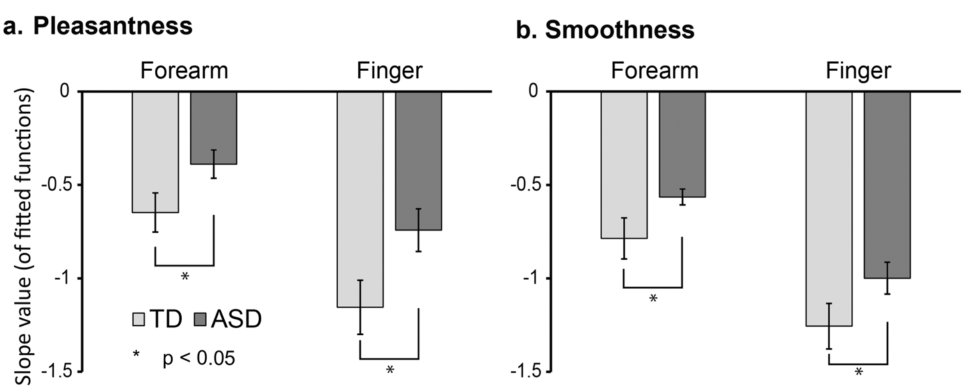

Fig. 4. Slope analyses. Slope values of linear function fitted to $\log_{10}$ normalized magnitude scores for (a) pleasantness and (b) smoothness instructions. Each data point represents the mean ± SEM of 40 participants. Asterisks indicate significant main effects of group in the four-way ANOVA (2 instructions × 2 body sites × 2 groups × 2 sexes).

spacing of 0.75 mm in both the main and supplementary experiments. The interdot spacing of 0.75 mm is close to the ridge-to-ridge distance of fingerprints (Králík & Novotny, 2003; Moore, 1989). Although the surfaces used in the present study differed from human skin, it is possible that the lower preference for smoother over rougher surfaces in individuals with ASD was associated with their lower preference for the surface structures of human skin, including that of the fingers.

We also found that smoothness decreased monotonically as a function of interdot spacing in both the ASD and TD groups. This result aligns with previous findings that interdot spacing monotonically increases perceived roughness in the general population (Kitada et al., 2012). It is unlikely that participants treated the two instructions identically, as the slope of smoothness estimates was significantly more negative than that of pleasantness estimates. Instead, smoothness and pleasantness appear to be related but distinct perceptual dimensions. In other words, they may rely on shared but partially distinct neural representations. This interpretation is consistent with neuroimaging findings showing that perceived roughness is negatively associated with activity in the parietal operculum and middle insula (Kitada et al., 2005), regions implicated in the affective processing of touch (Craig, 2002).

As compared with pleasantness, we observed less consistent group differences in smoothness between TD and ASD. Specifically, the interaction between interdot spacing and group was marginally significant, although the slope analysis indicated that slopes for both pleasantness and smoothness were more negative in the TD group than the ASD group. To our knowledge, no previous study has reported a trend for interaction between group and a physical determinant of roughness/smoothness (Haigh et al., 2016; O'Riordan & Passetti, 2006). However, one critical difference from these earlier reports is that, in our study, the participants' skin was stimulated with fixed movement speed and vertical force. Such control may have contributed to the emerging trend for group differences in smoothness perception, although further research is necessary to confirm this effect.

The observed trend toward reduced sensitivity of ASD participants to differences between smooth and rough surfaces suggests that common atypical factors may underlie both smoothness perception and its associated pleasantness. Our previous study demonstrated a clearer group × instruction interaction; unlike pleasantness, patterns of perceived softness were highly similar between the two groups (Makita et al., 2025). Therefore, it is unlikely that the present pattern can be explained solely by general differences in response scaling between groups. Instead, these findings raise the possibility that atypical processing is commonly involved in both the perception of smoothness and its associated pleasantness. This possibility warrants further investigation in future studies.

We observed a similar effect of body site in both groups: slope values were more negative for the fingers than for the forearm. This finding is consistent with previous work showing that the sensitivity of perceived magnitude to changes in interdot spacing is greater for the fingers than for the forearm (Kitada et al., 2012). The density of mechanoreceptors are greater in the fingers than in the forearm (Corniani & Saal, 2020), and mechanoreceptor composition also differs between them (Handler & Ginty, 2021). Compared with glabrous skin, hairy skin contains a higher density of C-tactile fibers, which are associated with pleasant interpersonal touch (Löken et al., 2009; Watkins et al., 2021), and these may have been activated in the present study. However, because the fingers (glabrous skin) are more sensitive to differences in interdot spacing, mechanoreceptors other than C-tactile fibers (Weber et al., 2013) are likely to contribute to pleasantness induced by 2D raised-dot patterns. Tactile inputs encoded by these receptors are thought to be transformed into intensity signals in the somatosensory cortex (Hsiao et al., 1993; Kitada et al., 2005) and subsequently into percepts of smoothness or associated emotional responses. It is possible that neural mechanisms involved in extracting such intensity signals, or in transforming intensity signals into valence, differ between individuals with ASD and TD.

Finally, a few limitations should be noted. First, participants evaluated smoothness only after completing the pleasantness session. Although the slopes for the two perceptual dimensions differed significantly, prior exposure to the pleasantness task may have influenced smoothness ratings. Second, we used rigid surfaces to prevent deformation that could alter the interdot spacing. However, to more directly address the relationship between surface textures and the structural properties of human skin, future studies should employ stimulus surfaces that more closely match the compliance and morphology of human skin.

Notwithstanding these limitations, in contrast to questionnaire-based measures, there is a growing need for more rigorous approaches to study atypical tactile processing in ASD such as psychophysical methods (Mikkelsen et al., 2018; Hadad & Yashar, 2022). The contribution of the present study is that we demonstrate atypical affective responses to tactile texture in ASD using controlled psychophysical experiments. Our finding is consistent with previous reports indicating atypical preferences for specific tactile textures in ASD (e.g., preference for coin textures; MacLennan et al., 2022). This psychophysical approach allows the identification of which tactile textures are preferred and under which physical conditions (e.g., interdot spacing). Psychophysical data can therefore provide quantitative predictions of affective responses to tactile stimulation in ASD under well-defined physical parameters. In this sense, together with a limited number of prior studies on tactile texture perception, the present work represents an important step toward understanding how affective responses in ASD relate to the physical characteristics of tactile stimulation. Such psychophysical measures may serve as quantitative behavioral phenotypes that could inform future efforts toward more individualized approaches in psychiatry.

In conclusion, the present study compared perceived pleasantness and smoothness between adults with ASD and TD controls when different body sites were stimulated with 2D raised-dot patterns. The decrease in pleasantness with increasing interdot spacing (i.e., physically rougher surfaces) was attenuated in ASD relative to TD participants. These findings suggest an atypical tactile preference for textured surfaces in ASD: although smoother surfaces were generally preferred over rougher ones, this preference was reduced in adults with ASD.

Abbreviations

AASP, Adolescent/Adult Sensory Profile
ADOS-2, Autism Diagnostic Observation Schedule

AQ, Autism-Spectrum Quotient
ASD, autism spectrum disorder
DISCO, Diagnostic Interview for Social and Communication Disorders
FSIQ, Full-Scale Intelligence Quotient
TD, typically developed control

Declarations

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Ethics approval and consent to participate

The study protocol was approved by the Research Ethics Committee of University of Fukui (protocol number: 20220104), and the local ethics committee at the Graduate School of Intercultural Studies, Kobe University (protocol number: 2022–4). All procedures were conducted in accordance with the Declaration of Helsinki and the Ethical Guidelines for Clinical Studies of the Ministry of Health, Labor, and Welfare of Japan. The participants received explanations regarding the purpose and meaning of the study, and written informed consent was obtained from all subjects.

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CRediT authorship contribution statement

Takuya Makino: Writing – review & editing, Investigation, Data curation. **Nodoka Sakakihara:** Writing – review & editing, Investigation. **Ayaka Fukuoka:** Writing – review & editing, Investigation. **Yuka Mizuno:** Writing – review & editing, Investigation. **Hirotaka Kosaka:** Writing – review & editing, Investigation, Funding acquisition, Data curation, Conceptualization. **Ryo Kitada:** Writing – review & editing, Writing – original draft, Supervision, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Kai Makita:** Writing – review & editing, Writing – original draft, Investigation, Formal analysis, Data curation.

Declaration of Competing Interest

The authors declare that they have no competing interests.

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Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.reia.2026.202873.

Data availability

Data will be made available on request.

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