Molecular Autism

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Reduced relationship-specific social touching and atypical association with emotional bonding in autistic adults

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Abstract

Background Autism spectrum disorder (ASD) is a neurodevelopmental disorder defined by social communication deficits, repetitive behaviors and restricted interests. Studies have reported aberrant sensory responses, including altered experiences of social touch, in individuals with ASD. However, the relationship between atypical social touch and social networks in ASD remains poorly understood. Social touch is used to strengthen and manage social networks in many species. Studies in general populations across diverse cultures show that the extent of permissible touch is consistently linked to the strength of emotional bonds between the toucher and the touched individual. This study examined relationship-specific patterns of social touch and their association with emotional bonding in individuals with ASD.

Methods Seventy adults with ASD and 70 typically developed (TD) adults rated their emotional bonds with different social network members (e.g., partners, fathers, strangers) and the pleasantness of being touched by each. Participants also identified body regions where they allowed touch. We hypothesized that patterns of interpersonal touch allowance and emotional bonding, and their relationship, would differ between ASD and TD adults.

Result In all social network members except children and female friends, ASD adults allowed significantly less social touching than TD adults. Compared to TD adults, ASD adults also reported having significantly weaker emotional bonds with one social network member and experiencing significantly less pleasantness when touched by multiple members of their social network. In both groups, strength of emotional bond was significantly correlated with permissible touch area. Linear regression analyses showed that our ASD participants were more reliant on bodily touch allowance for emotional bonding than the TD controls.

Limitations More participants are necessary to secure sufficient number of social network members in ASD.

Conclusions Our results suggest that adults with ASD generally prefer less social touch from most social network members and show reduced emotional bonding with only a specific connection. In addition, touch allowance was more strongly associated with emotional bonding in ASD than TD adults. These findings highlight the influence of autistic traits on the relationship between social touch and emotional bonding within social networks.

Keywords Social touch, Social network, Emotion, Pleasantness, Social closeness

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Background

Autism spectrum disorder (ASD) is a neurodevelopmental disorder characterized by core symptoms of impaired social communication and restricted, repetitive patterns of behavior. Aberrant responses to sensory stimuli have also long been reported as characteristic of ASD [1] and they manifest in various forms [2, 3]. Sensory symptoms in ASD have been observed across age and intellectual levels [4], and sensory abnormalities were added to the diagnostic criteria for ASD (DSM-5: Diagnostic and Statistical Manual of Mental Disorders, 5th edition) [5].

Interpersonal touch, a form of physical social communication through activities such as shaking hands and hugging, is a critical part of human social communication. Touch with close others contributes to cognitive and socioemotional development in childhood [6, 7] and promotes the formation of social relationships as well as psychological and physical well-being in adulthood [8–10]. A shortage of interpersonal touch is associated with anxiety, stress, depression, and feelings of loneliness in the general population [11–13]. Previous studies have reported aberrant tactile processing in individuals with ASD [8, 14–16] and indicated that atypical touch behaviors in individuals with ASD may be associated with their core symptoms [17–21].

Among the few studies that have directly examined responses to interpersonal touch in ASD, there is general consensus that individuals with ASD show atypical responses to interpersonal touch [22–25]. For example, studies using a self-questionnaire on interpersonal touch (Social Touch Questionnaire, [26]) have shown that adults with ASD exhibit a reduced appreciation of giving, receiving, and witnessing interpersonal touch in daily life [22, 23], and a study using an alternative self-questionnaire found that some adults with ASD simply feel uncomfortable being touched by others [24]. A study examining the effect of social context on social touch found that adults with ASD reported lower levels of pleasantness, erogeneity, and appropriateness in dating and dance class contexts [25]. Collectively, these studies suggest that adults with ASD have a reduced appreciation of interpersonal touch. However, it remains unclear how atypical interpersonal touch in ASD relates to the presumed social functions of interpersonal touch.

One of the functions of social touch that has been attracting growing interest is the role it plays in the formation of social structures by promoting affective relationships with others. For example, non-human primates dedicate a significant amount of time to grooming others, far exceeding the time required for the practical necessity of removing parasites or debris from their fur [27]. This social grooming plays a crucial role in forming social bonds, resulting in greater social closeness that is reflected in increased prosocial behaviors [27, 28]. These findings suggest that differences in social touch patterns may be linked to variations in social structure. In previous research, we surveyed 1,368 adults from the general populations in Western countries (Finland, France, Italy, Russia, and the UK) and 255 individuals from Japan, asking where on their bodies they would permit relatives, friends, and strangers to touch them [29, 30]. We also assessed the emotional bonds between participants and touchers, as these bonds are key predictors of social contact and reflect individuals' positions within social networks [31, 32]. Regardless of the country, the extent of the topographic map of body areas that were acceptable to touch was associated with the strength of the emotional bond between the participant and the toucher. This finding aligns with the idea that relationship-specific patterns of social touch support the establishment and maintenance of social structures and affective relationships among humans, irrespective of cultural differences [29, 30]. However, to our knowledge, no previous study has explored relationship-specific patterns of social touch and their association with emotional bonding in individuals with ASD.

Here, we compared relationship-specific social touching patterns between typically developed (TD) adults and adults with ASD. We used a high-resolution self-reporting tool (emBODY) to quantify relationship-specific maps of bodily regions where social touch was allowed. Participants evaluated their emotional bonds with, and the pleasantness of being touched by, members of their social networks, ranging from close relatives (e.g., parents and siblings) to strangers. They then indicated which areas of the body they allowed each network member to touch. We hypothesized that the relationship between the touch allowance map and emotional bonding would differ between adults with ASD and those with TD. Initially, we tested our prediction that adults with ASD would report a smaller touchable body area and lower pleasantness from social touch compared to TD individuals, regardless of the social network member. We then tested our prediction that emotional bonds with social network members would be weaker in adults with ASD, because many adults with ASD experience loneliness more frequently [33, 34] and report less social closeness with others [35]. Finally, we predicted an atypical relationship between touch permissibility and emotional bonding in ASD, such that a smaller increase in touch allowance within social networks would be associated with a smaller increase in emotional bonding.

Methods

Participants

Seventy Japanese TD adults and 70 adults with ASD participated in the study (140 participants in total). A sample size estimation using G*Power [36] indicated that at least 64 participants per group were required to achieve a power of 0.8 for a medium to large effect size (Cohen's d > 0.5), as observed in previous studies [22, 23]. Both samples were studied *in-person* to measure intellectual ability and minimize satisficing, i.e., the tendency of online participants to provide satisfactory answers without appropriate cognitive effort. The two groups were matched for mean age, sex ratio, and handedness (see Table 1). Written informed consent was obtained from all participants after a complete explanation of the study. The study protocol was approved by the local ethics committees at University of Fukui (Japan) (protocol number: 20210117) and the Graduate School of Intercultural Studies, Kobe University (protocol number: 2021–2, 2022–4). All methods were carried out in accordance with the approved guidelines and the Declaration of Helsinki.

Cognitive ability of each participant was assessed by the Wechsler Adult Intelligence Scale-Third Edition (WAIS-III) or Fourth Edition (WAIS-IV) [37, 38], or by a short form of the WAIS-III [39]. A full-scale IQ of at least 70 was required for inclusion in the study. We also measured the Autism-Spectrum Quotient (AQ) total score [40] to confirm autistic traits, and the scores on the four quadrants of the Adult/Adolescent Sensory Profile (AASP) [41]: low registration, sensation seeking, sensory sensitivity and sensation avoiding.

ASD group (main experiment)

Seventy adults with ASD [44 male, 31.6 ± 8.4 years (mean ± SD)] participated in the experiment at the University of Fukui Hospital (Japan) (Table 1). These participants were diagnosed with ASD based on the DSM-5 classifications [5] by an experienced clinician (H.K.) and standardized criteria using the Diagnostic Interview for Social and Communication Disorders (DISCO) [42]. In a majority of the ASD participants (42/70), ASD diagnosis was also confirmed by the Autism Diagnostic Observation Schedule (ADOS-2, Module 4); the mean ± SD of Calibrated Severity Scores was 7.9 ± 1.0 [43, 44]. Some individuals with ASD reported comorbidity of attention deficit hyperactivity disorder (ADHD; n = 5), adjustment disorder (1), anxiety disorder (3), bipolar disorder (2), depression (11), eating disorder (1), epilepsy (1), idiopathic hypersomnia (1), and obsessive compulsive disorder (2).

TD group (main experiment)

Seventy Japanese TD adults [44 male, 30.0 ± 8.4 years (mean ± SD)] participated in the study at Kobe University and the University of Fukui. The mean age and sex ratio of TD participants were matched with those of the ASD group (Table 1). No participants reported any psychiatric disorders.

Table 1 Demographic data and rating scale scores

	TD	ASD	T-value	*P*-value	Effect size (d)
Number	70	70	–	–	–
Sex (male/female)	44/26	44/26	–	–	–
Age (years)	30.0 ± 8.4	31.6 ± 8.4	1.15	0.25	–
FSIQ	108.4 ± 13.5	104.4 ± 13.3	1.90	0.06	–
AQ					
Total score	17.8 ± 7.2	34.2 ± 6.4	14.31	< 0.001	2.42
Social skill	3.9 ± 2.8	8.1 ± 2.2	10.02	< 0.001	1.69
Attention switching	3.9 ± 1.9	7.6 ± 1.6	12.67	< 0.001	2.14
Attention to detail	4.7 ± 2.2	5.9 ± 2.3	3.21	0.002	0.54
Communication	2.7 ± 2.1	7.0 ± 2.2	12.04	< 0.001	2.04
Imagination	2.6 ± 1.8	5.5 ± 2.2	8.38	< 0.001	1.42
AASP					
Low registration	29.4 ± 7.9	37.5 ± 8.4	5.90	< 0.001	1.00
Sensation seeking	42.3 ± 6.6	31.9 ± 7.3	8.88	< 0.001	− 1.50
Sensory sensitivity	36.9 ± 9.4	45.7 ± 9.9	5.39	< 0.001	0.91
Sensation avoiding	37.4 ± 9.3	47.6 ± 10.4	6.14	< 0.001	1.04
Touch	31.7 ± 7.1	35.5 ± 7.1	3.22	0.002	0.54

ASD autism spectrum disorder, *TD* typically developed control, *AQ* Autism Spectrum Quotient, *AASP* Adolescent/Adult Sensory Profile. *FSIQ* (Full-Scale Intelligence Quotient) were calculated from the WAIS-III, WAIS-III short form and WAIS-IV. Age, AQ, and AASP scores are shown as mean ± SD. T and *p*-values were the result of independent-samples t-tests comparing TD and ASD (without family-wise error correction)

We excluded participants who reported during the recruitment process or upon providing informed consent that they had been diagnosed with ASD.

Pilot online experiment

Our previous study recruited more than 200 adults in the general Japanese population [30]. Before conducting the main experiment, we assessed whether a sample of 70 adults from the general population would be sufficient to observe results similar to those in the previous study [30]. In this preliminary experiment, 70 Japanese adults (41 male, mean age 31.0 ± 7.9 years) participated in an online survey conducted by a research firm (MyVoice Communications, Tokyo). These individuals did not participate in the main experiment. The mean Autism-Spectrum Quotient (AQ) total score was 24.4 ± 7.8, with 9 participants (13%) exceeding the cut-off value of 32. We confirmed that a sample size of 70 participants per group would be sufficient to observe both the relationship-dependent touch allowance maps and the correlation between emotional bonding and touch allowance (Supplementary Fig. 1).

Data acquisition

We developed the Japanese version of the body-painting tool emBODY [29, 30] using an online experiment platform (Gorilla.sc, https://app.gorilla.sc). In all experiments, the participants used the same type of tablet (iPad Air, Apple Inc.) and stylus (Apple Pencil; Apple, Cupertino, CA). The diameter of the painting tool was set to 11 pixels. Intellectual ability was assessed on a separate day from the experiment. Regardless of the site or group, the experiment was conducted in person by an experimenter in a quiet room.

We followed the same procedure as in our previous study [30]. Participants first provided background information about themselves and members of their social network. They were given a list of candidate male and female social network members (partner, children, mother, father, sister, brother, niece, nephew, aunt, uncle, male and female cousins, male and female friends, and male and female acquaintances). The term "partner" referred to an individual who was married to, living with, or dating but not cohabiting with a participant. We also included "female stranger" and "male stranger" to assess acceptable social touch with strangers. Next, for each candidate network member, participants indicated if they had one or more individuals from these categories in their own social network. If participants had multiple individuals fitting one category (e.g. multiple brothers), they were instructed to choose just one. The participants provided details about the sex (only for partners and children) and ages of the selected social network members, along with approximations of the amount of time since their last encounter. For strangers, we assumed they were of similar age to the participants and set the time since the last encounter to 0 days (since most people meet unfamiliar individuals daily). These strangers were then referred to as "a woman/man of your age who you don't know." In subsequent questions, participants rated their emotional bond with each network member on a scale from 1 (no emotional bond) to 10 (the strongest emotional bond). They also provided estimates of how pleasant it would be to be touched by each social network member, using a scale from 1 (not pleasant at all) to 10 (extremely pleasant).

After answering the background questions, participants completed the mapping of the touch allowance zones with the emBODY tool. They were instructed to consider which areas of their bodies they would deem acceptable for each social network member to touch them in everyday situations. Participants were presented with front and back body outlines along with the name of a specific social network member (e.g., your mother) and were asked to use a stylus to color the areas where they would allow that individual to touch them. They repeated the task twice for each network member and selected the map they felt was most accurate. To ensure sustained attention during the task, a separate catch trial was included. In this trial, participants were instructed to color both arms of the body outline. After completing the body mapping task, participants then filled out the AQ [40] and AASP [41].

Data analysis

Data preprocessing

We used MATLAB (R2022b, Mathworks, Natick, MA, USA) and SPSS (version 27, IBM Corp., Armonk NY, USA) for analyses. We first checked the data for completeness and confirmed that participants performed the catch trial correctly. Data from the coloring tasks were then converted to 2-dimensional MATLAB matrices, where each cell represented a pixel on the body. The data matrices (front and back) were resized to 612 × 306 pixels each. The colored images were binarized so that the amount of time a participant spent on coloring an area would not affect the results. Each participant completed between 2 and 18 individual touch area maps (TAMs), depending on the size of their social network. We spatially smoothed each TAM for each individual using a 2D Gaussian filter (with 4 standard deviations of Gaussian distribution).

Comparing the samples using two-proportion z-test

We compared the acceptable touch areas of the TD and ASD groups by comparing pixelwise mean intensities

using a two-tailed two-proportion z-test with a statistical threshold of 0.05, corrected for the false discovery rate (FDR) [45]. The FDR procedure controls the fraction of positive inferences that are false. Specifically, we used the two-proportion z-test to obtain *p*-values for each pixel from each body map. These *p*-values were then ranked in ascending order, and the q-values (pFDR) were calculated by multiplying the total number of tests by the *p*-value and dividing by its rank. The analysis was conducted separately for each body map, without assuming any correlations between pixels. Because we had an a priori hypothesis that there would be significant group differences in the body maps for each social network member, we did not apply multiple comparison corrections across body maps. This approach is analogous to mass univariate analyses in functional MRI studies [46].

To examine the association between emotional bonding with network members and the corresponding touchable body areas, we first calculated a touchability index (TI), defined as the proportion of colored pixels within the body outline for each TAM, and ranging from 0 to 1 [29, 30]. To quantify the differences in the topographies of acceptable touch, we also defined eight anatomical regions of interest (ROIs: arms, crotch/bottom, feet, hands, head, legs, shoulders, and torso) and calculated ROI-specific TIs as the proportion of colored pixels within each. We then conducted multiple linear regression analysis using the mean emotional bond with each social network member as the dependent variable, and group (ASD and TD), sex, and mean TIs as explanatory variables. To confirm the results, we conducted additional analyses using a summary statistics approach [46]. First, for each participant, we conducted a simple linear regression analysis of emotional bonds with social network members with TIs as exploratory variables (individual analysis). Subsequently, we conducted a two-way ANOVA (group × sex) on parameter estimates of TIs that were obtained from the individual analysis.

Results

Demographic data

Table 1 shows the demographic data. Two sample t-tests showed that the AQ total score was significantly higher for the ASD than the TD group [$t(138) = 14.31$, $p < 0.001$, Cohen's $d = 2.42$]. AASP scores were significantly higher in the ASD group for the quadrants of low registration, sensory sensitivity, and sensation avoiding, while the score for sensation seeking was significantly greater in the TD group (all *p*-values < 0.001, two-sample t-tests). Finally, touch rating for AASP was significantly greater for ASD than TD [$t(138) = 3.22$, $p = 0.002$, Cohen's $d = 0.54$].

Number of social network members

We compared the number of social network members between the ASD and TD group (Supplementary Table 1). A two-sample t-test showed that the total number of social network members (except strangers) was significantly lower for ASD (9.70 ± 0.25, mean ± SEM) than TD participants (10.99 ± 0.27) [$t(138) = 3.50$, $p = 0.001$, Cohen's $d = 0.59$]. Two-proportion z-tests showed that the ASD group had significantly lower numbers of partners [FDR-corrected *p*-value (pFDR) < 0.001], children (pFDR = 0.01), and female and male friends (pFDR < 0.001) than the TD group. Notably, 15 of the TD participants and 3 of the ASD participants had children.

TAMs for ASD and TD individuals

Figure 1a,b shows the mean TAMs for different social network members in the ASD and TD samples. The relationship-specific TAMs were generally consistent across samples. Specifically, their partners and children were allowed to touch more areas of the body than other members, and closest relatives were more likely to be permitted to touch the head and shoulders. In contrast, adult strangers were restricted to touching only the hands. Direct comparison of TAMs between ASD and TD participants using two-proportion z-tests revealed that the TD participants allowed more touching from all members except children, nephews and female friends, compared to ASD participants (Fig. 2 and Supplementary Fig. 2 for unthresholded data). Greater degree of touch allowance was observed on the back side of the body for most social network members. No body area was significantly more touchable by ASD participants compared to TD participants.

Emotional-bond and pleasantness ratings

Figure 3ab shows boxplots for emotional-bond and pleasantness ratings for both groups (see Supplementary Table 2 for mean and SEM). In both groups, individuals reported the strongest emotional bond with their partners and children, followed by their closest family members and relatives. The weakest emotional bond was reported with strangers. The strength of the emotional bond with friends largely fell between that of primary and extended family members in both samples. Wilcoxon rank sum tests (with FDR correction over social network members) showed that the emotional bond with male cousins was significantly lower in ASD than in TD participants (pFDR = 0.04). Non-significant trends indicating greater emotional bonds in TD participants compared to ASD were also observed for mothers, fathers, sisters, brothers, nephews, aunts, uncles, female cousins, male friends and female adult strangers (pFDR values < 0.07;

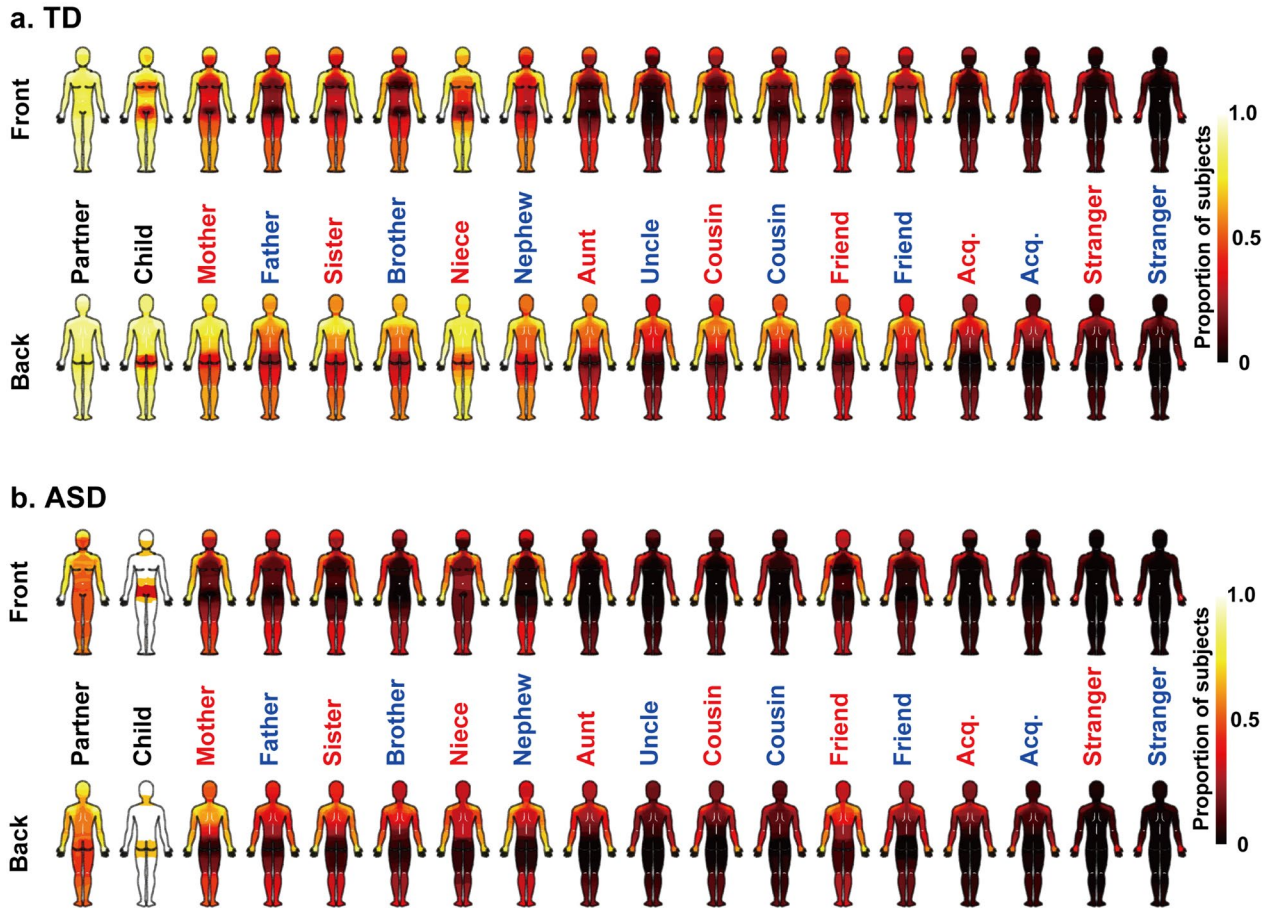

Fig. 1 Relationship-specific TAMs in (**a**) TD and (**b**) ASD participants. The coloring displays the proportion of the sample reporting that being touched by each person in this area would be acceptable. Red and blue fonts indicate female and male network members, respectively; Acq. indicates acquaintances

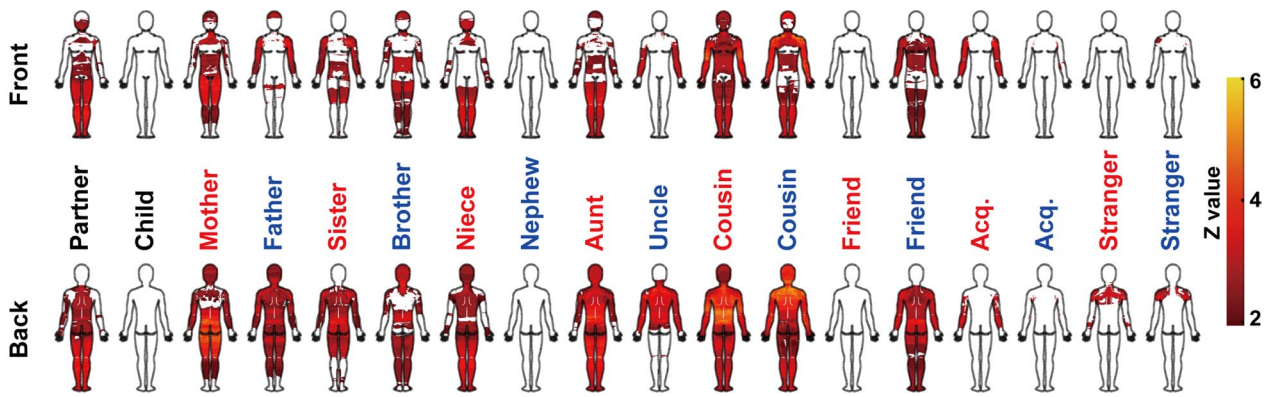

Fig. 2 Statistical maps for the touch allowance differences (TD > ASD) between the groups. Red and blue fonts indicate female and male network members, respectively; Acq. indicates acquaintances. Red and yellow areas represent significantly higher touch allowance for TD participants, whereas the white areas on each body map indicate no significant difference. No body area was more accessible for ASD participants than TD participants. The data are thresholded at $p < 0.05$ with FDR correction in each body map. See Supplementary Fig. 2 for unthresholded data

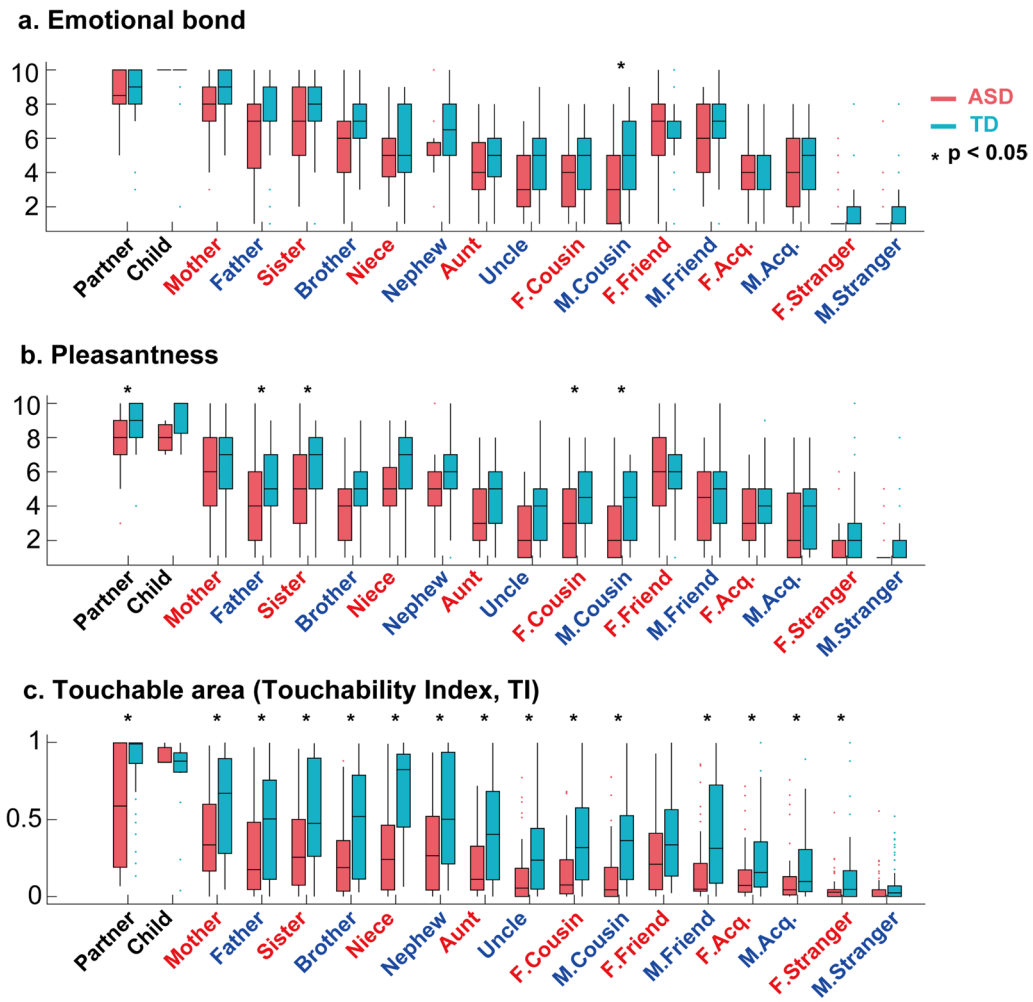

Fig. 3 Boxplots of emotional bonds (**a**), pleasantness (**b**), and touchability index (TI) (**c**). Dots indicate outliers (the interquartile % range). TI ranges from 0 to 1. Asterisks indicate the significant results from Wilcoxon rank sum tests (with FDR correction over social network members). F. and M. indicate female and male, respectively

Supplementary Table 2). None of the social network members showed a significantly stronger emotional bond for ASD than TD participants.

Participants reported that being touched by their partner and children elicited most pleasantness, followed by their close relatives and friends. Wilcoxon rank sum tests (with FDR correction) on pleasantness ratings revealed significantly greater pleasure for TD participants than for ASD participants from touch by partners, fathers, sisters, and both female and male cousins (pFDR values < 0.05). Non-significant trends for greater emotional pleasantness in TD participants compared to ASD participants were also observed for mothers, brothers, uncles, and female acquaintances (pFDR values < 0.08; Supplementary Table 2). Pleasure ratings were not higher for ASD participants compared to TD participants for any social network member.

Touchable area

Figure 3c shows network member-specific touchability indices (TIs; the proportion of pixels on the body that a particular member of the participant's social network was allowed to touch) for both groups. Wilcoxon rank sum tests (with FDR correction) on TIs revealed a significantly greater TI in TD participants than in ASD participants for all network members except children, female friends, and male strangers (pFDR < 0.05); the effect for female friends showed a trend toward significance ($p = 0.066$).

The relationship between emotional bonding, pleasantness and TI

Figure 4 depicts the correlations among TI, pleasantness, and emotional bonding. We excluded children from the plots because only three participants in the ASD group

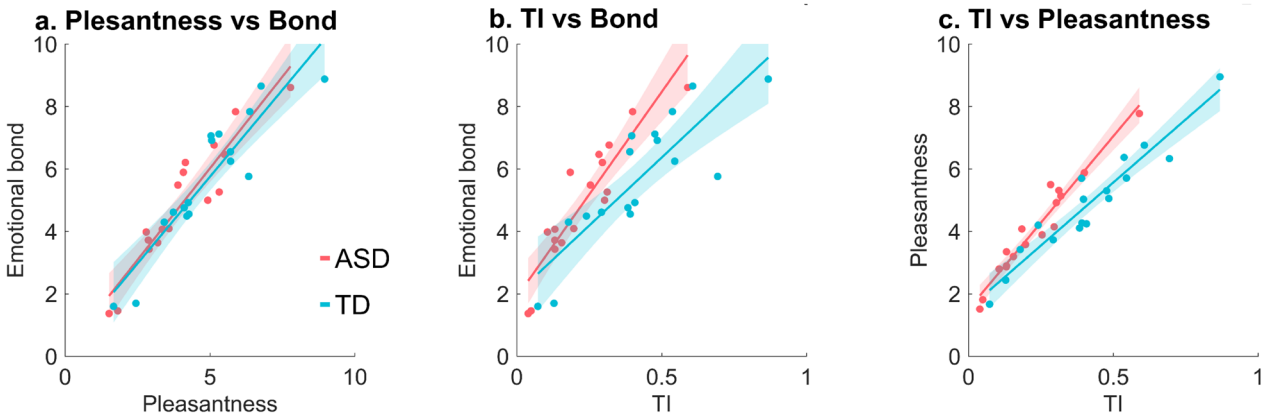

Fig. 4 Correlations among touchable area, emotional bonding and pleasantness. Each dot represents the average response for one member of the social network in each group (e.g., mother of TD participants), with a linear regression line and confidence interval for the regression fitted separately for each group. TI indicates the touchability index, which ranged from 0 to 1

had children. We then conducted a linear regression analysis to predict the mean emotional bond score using mean TI, group and sex as explanatory variables. The results showed that these variables collectively explained 72% of the variance in emotional bonding (adjusted $R^2 = 0.72$). Emotional bonding was significantly predicted by the TI [$\beta = 10.42$, $t(61) = 12.58$, $p < 0.001$] and TI × group interaction [$\beta = 2.18$, $t(61) = 2.64$, $p = 0.011$]. As a supplementary analysis, we repeated the same analysis using a summary statistics approach; we performed the linear regression analysis on emotional bonding with TI as an explanatory variable *for each participant* and obtained parameter estimates (β, slope values) of TI for all participants. We then conducted a two-way ANOVA (two groups × two sexes) on these β values. This analysis confirmed that the slope was significantly greater for the ASD group than the TD group. More specifically, we observed a significant main effect of group regardless of whether all members were included [$F(1, 136) = 7.04$, $p = 0.009$, $\eta_p^2 = 0.049$] or children were excluded [$F(1, 136) = 6.23$, $p = 0.014$, $\eta_p^2 = 0.044$]. No other effects were observed.

We next performed a linear regression analysis to predict mean pleasantness using mean TI, group and sex as explanatory variables. This analysis revealed that the variables explained 90% of the variance in pleasantness (adjusted $R^2 = 0.90$). TI [$\beta = 9.41$, $t(61) = 21.07$, $p < 0.001$] and TI × group interaction [$\beta = 1.48$, $t(61) = 3.31$, $p = 0.002$] significantly predicted pleasantness. We again applied a linear regression analysis with TI as an explanatory variable for each participant and confirmed a significantly greater slope for the ASD group compared to the TD group. More specifically, a two-way ANOVA (two groups × two sexes) on parameter estimates confirmed a significant main effect of group regardless of whether all members were included [$F(1, 136) = 9.56$, $p = 0.002$, $\eta_p^2 = 0.066$] or children were excluded [$F(1, 136) = 7.64$, $p = 0.007$, $\eta_p^2 = 0.053$]. No other effects were observed. Taken together, these results showed that the TI explained emotional bonding and pleasantness differently between ASD and TD.

Sex differences

We next examined whether the sex of social network members influenced touch acceptance similarly in the TD and ASD participants. Figure 5 shows the relationship between touchable body area and the sex of the toucher for the male and female participants in both groups. To statistically evaluate the effect of sex on TI, we conducted an ANOVA on the TIs of participants and touchers in both groups. For partners, because the sex of the partner was usually determined by the sex of the participant, it was difficult to compare the effect of sex on TI between the two groups. Additionally, because only a few ASD participants (2 female and 1 male participant) had children, we excluded the partner and child data from this analysis.

Three-way ANOVA (2 levels of group × 2 levels of toucher sex × 2 levels of participant's sex) on the TI revealed a significant main effect of group [$F(1, 136) = 25.13$, $p < 0.001$, $\eta_p^2 = 0.16$], such that the TIs in the TD group were larger than the TIs in ASD group. The main effect of toucher's sex was also significant [$F(1, 136) = 60.39$, $p < 0.001$, $\eta_p^2 = 0.31$], with female touchers allowed to touch larger areas than male touchers. The effect of participant's sex was not significant ($p = 0.15$). We also observed a significant interaction between the participant's sex and toucher's sex [$F(1, 136) = 56.37$, $p < 0.001$, $\eta_p^2 = 0.29$]. Post hoc paired t-tests showed that TIs for female touchers were significantly larger

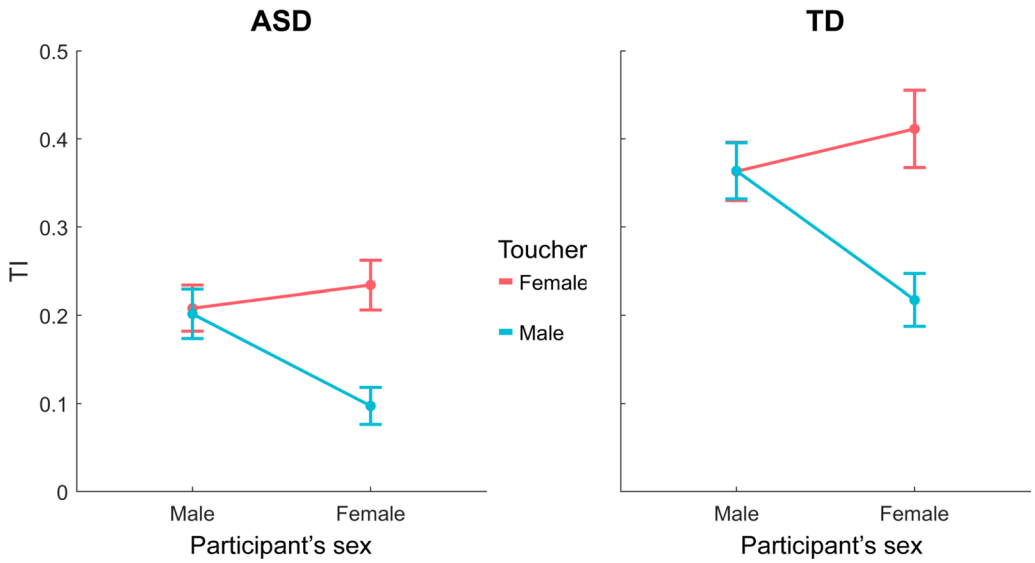

Fig. 5 Sex difference. Interaction plot of the average TI for male and female participants with respect to male and female touchers (blue and red dots, respectively) for each group (TD and ASD) are shown. Error bars depict SEM. Note: partners and children were excluded from the analyses, as the sex of partners and children can differ by participants and groups

than those for male touchers among female participants [$t(25) = 6.65$ $p < 0.001$, $d = 1.30$ for ASD; $t(25) = 9.22$ $p < 0.001$, $d = 1.80$ for TD], but not among male participants (p-values > 0.6).

Region-of-interest analysis

Whole-body TAM analyses revealed group differences in the touchability of specific body areas. To further examine for region-specific group differences, we next conducted linear regression analyses to predict emotional bonds with regional TI, sex and group as the explanatory variables (Fig. 6). We excluded children from the analysis because there were few children in the social network of the ASD group. The results showed significant effects of regional TI in all body areas (p-values < 0.001). Moreover, significant interactions between TI and group were observed for several body parts; that is, there was a greater rate of increase in bonding as a TI (slope) for ASD than TD in the following body areas: feet [$\beta = 2.80$, $t(61) = 2.87$, $p = 0.006$], head [$\beta = 1.76$, $t(61) = 2.21$, $p = 0.03$], legs [$\beta = 3.70$, $t(61) = 3.77$, $p < 0.001$] and torso [$\beta = 2.06$, $t(61) = 2.24$, $p = 0.029$]. There was a trend toward significance for the crotch ($p = 0.054$). In all of these ROIs, the emotional bond was more strongly dependent on changes in TIs (steeper slope) in the ASD sample.

To confirm the results of the ROI analysis, we also ran the linear regression analyses with emotional bonding as a dependent variable and TI as an explanatory variable for each participant and conducted two-way ANOVA (group × sex) on parameter estimates of TI between groups. We confirmed a significant main effect of group for legs, crotch and torso, regardless of whether all members were included or children were excluded (p-values < 0.05). Collectively, the results of this complementary analysis confirmed that the association between emotional bonding and TI in the legs, crotch and torso was stronger in ASD than TD participants.

Discussion

Our main findings are threefold. First, the body areas that most social network members were allowed to touch were significantly smaller in adults with ASD compared to TD adults. Second, adults with ASD reported significantly lower pleasantness and significantly weaker emotional bonds with one or more social network members compared to TD adults. Third, although the touchable area was linearly correlated with emotional bonding in both the ASD and TD groups, the dependence of emotional bonding on the touchable area was greater in adults with ASD than TD adults.

Overall, our results showed the relation-specific allowance of social touch in both ASD and TD in everyday situations; participants granted the inner layers of their social network, such as their partners and close relatives, more permission to touch them compared to strangers. In previous studies, a similar relation-specific touch allowance was observed in the general population [29, 30]. However, at the same time, we found group differences that supported our hypothesis: adults with ASD

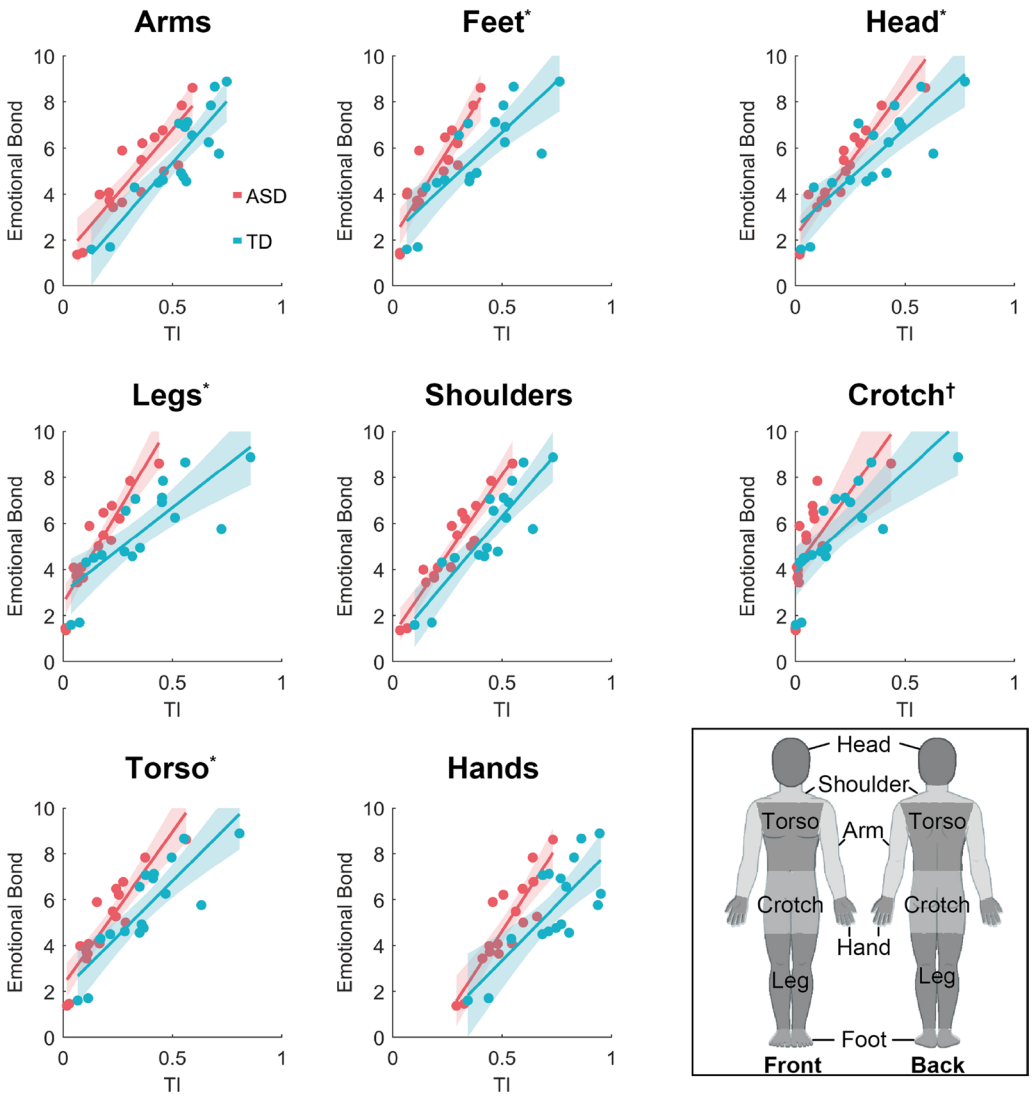

Fig. 6 Regional group differences in the association between TI and emotional bonding. Least-squares regression lines were fitted to each group separately. Each dot represents the average response for one member of the social network (e.g., 'ASD partner'). Symbols indicate interaction between TI and group (*$p < 0.05$; †$p = 0.054$)

allowed others to touch fewer areas of their bodies than TD adults across most social network members. This result indicates that being touched by social network members in everyday situations is less acceptable for adults with ASD than for TD adults. Survey studies have indicated that adults with ASD have more negative attitudes and thoughts toward social touch compared to TD adults [22–25]. Our study extends these previous findings by showing that adults with ASD vary their touch permissibility depending on the social network member, while allowing touch in fewer body areas compared to their TD counterparts, when touched by most social network members.

Sex differences in touchable areas were similar between ASD and TD, though the total touchable area was greater for TD adults than for those with ASD. In both groups, female participants allowed women to touch a greater area of their body than men, whereas male participants did not show a clear preference for touch by males versus females. This result closely corresponds with previous findings from the general Japanese population [30]. These similarities suggest that tactile allowance patterns may be relatively consistent between ASD and TD, despite overall differences in the total touchable area.

In the present study, touchable body area was correlated with pleasantness ratings in both TD and ASD

adults. A previous study showed that, compared to TD adults, ASD adults considered being touched by others less appropriate and pleasant in friendly and intimate social contexts [25]. Thus, while touch permissibility can be related to multiple factors, pleasantness is likely a key factor related to touchable body area in ASD. As we predicted, being touched by social network members was significantly less pleasant for ASD adults than for TD adults. One explanation for the reduced pleasantness in ASD could be heightened tactile sensitivity. Indeed, ASD adults in the present study reported greater sensory sensitivity and sensation-avoiding scores on the AASP questionnaire than TD participants, while sensation seeking scores showed the opposite pattern. This result, which was consistent with some previous findings [47, 48], suggests that ASD participants in our study have a lower neurological threshold for sensory stimuli, according to Dunn's model [2]. This explanation is also supported by previous studies showing heightened sensitivity to non-social tactile stimulation, such as a lower detection threshold for vibration, in ASD adults [49, 50]. Thus, it is possible that a reduced neurological threshold for tactile stimulation contributes to reduced social touch allowance, as well as decreased pleasantness.

On the other hand, we also found that pleasantness ratings for contact with certain social network members, such as children and friends, were comparable between the ASD and TD groups. Moreover, touch from a few social network members, such as children and female friends, was similarly acceptable between the two groups. These results indicate that the reduction in pleasantness and touchable body areas in ASD is likely influenced by factors beyond heightened tactile sensitivity. Indeed, a recent psychophysical study demonstrated that adults with ASD showed less preference than TD adults for touching polyurethane rubber whose physical softness was similar to human body parts though the perceived softness patterns between TD and ASD were highly similar [51]. Additionally, the details of the interpersonal touching, such as the toucher's sex and social closeness, strongly influence the perceived pleasantness of social touch and the underlying brain networks in the general population [52–54]. It is possible that atypical affective processing of touch in ASD, involving both bottom-up and top-down processing, makes social touch less pleasant and leads individuals to consider their body as less touchable by others.

In the present study, emotional bonding with male cousins was significantly lower in the ASD than the TD group, while the bonding with other social network members tended to be lower in ASD participants, but not significantly so. This finding partially supports our prediction that emotional bonding with social network members is reduced in ASD. A previous study showed that ASD adults reported less social closeness with others [35]. We here extended this finding by revealing relation-specific patterns of emotional bonding among adults with ASD. The reduced emotional bonding observed in our study aligns with previous studies showing that individuals with ASD experience loneliness more frequently than TD adults [33, 34]. This result is also consistent with our finding that adults with ASD had smaller social networks than TD adults.

Contrary to our prediction, however, emotional bonding with certain social network members, such as friends and acquaintances, was comparable between the ASD and TD groups. A previous study showed that intimate relationships and best friendships can be of similar quality between ASD and TD adults [35], whereas children with ASD tend to have fewer friends and experience poorer-quality friendships than their TD counterparts [55, 56]. Therefore, the reason that the reduction in emotional bonding with others was less pronounced than expected in our study may be that adults with ASD can experience strong emotional bonding with their social network members, despite having a smaller social network than TD adults.

Another finding in the present study was that emotional bonding was linearly dependent on the total touchable area by social network members in both TD and ASD. These results suggest that the extent of touch permissibility in ASD is strongly influenced by the emotional bond with the toucher. To our knowledge, this study is the first to demonstrate an association between touch allowance and emotional bonding in adults with ASD. This association is in accord with proposed functions of social touch. That is, social touch can elicit positive emotions and is generally considered a positive social signal [57–62]. For example, participants from the general population evaluate even a stranger more positively, if that person has inconspicuously touched them during an interaction [58–60]. This link between touch and impression formation indicates that touch may play a causal role in forming social bonds. Interpersonal touch can influence prosocial behavior, such as complying with requests and increased generosity in tipping, even if the touch is subtle [61, 62]. Thus, social touching could be the means of conveying a willingness to offer subsequent help, thus forming the basis of mutual exchanges of social support.

As we predicted, we observed an atypical association between emotional bonding and touch allowance in ASD, but with different patterns. In adults with ASD, touchable areas more strongly predicted emotional bonding than in TD adults. This group difference in overall touchability was evident in specific body regions, including the legs, torso, and crotch. One possible explanation is that even a

small amount of social touch can play a significant role in shaping feelings of social closeness in ASD. Although it has been reported that adults with ASD tend to be reluctant to be touched by others [23–25], many individuals with ASD anecdotally express a craving for touch. Temple Grandin, an animal scientist with ASD expresses the paradox succinctly: "Our bodies cry out for human contact, but when contact is made, we withdraw in pain and confusion" [63]. However, she has also noted a preference for warmth and strong pressure, such as a firm hug, suggesting that certain forms of social touch may be enjoyable for individuals with ASD. Similarly, Donna Williams, another woman with ASD, has written "I learned to trust her daughter enough to let her brush my hair and tickle my feet and forearms, and this allowed me to experience the pleasure and relaxation I could get from touch, albeit in a very primitive form" [64]. Thus, while this cross-sectional study cannot determine causal relationships among emotional bonding, pleasantness, and touchable areas, it is possible that once individuals with ASD allow others to touch them, they will experience the pleasure of social touch, leading to a greater emotional bond with the toucher. This speculation aligns with our finding that, although ASD adults permit less touch from most of their primary family members (e.g., partners), their emotional bond with these members is as strong as that of TD adults. It is possible that even a slight increase in touch permissibility could result in a relatively greater increase in emotional bonding.

Limitations

Several interpretational issues and limitations bear mention. First, participants with ASD had significantly fewer partners, children, and friends than TD participants. To minimize the effect of such group differences on the analysis of the relationship between touchable body area and emotional bonding, we conducted linear regression analyses on both the averaged group data and the individual data, and found similar results with both approaches. Thus, it is unlikely that these differences account for the group differences in the linear relationship between emotional bonding and touchable body area. However, this limitation could be addressed in future studies with larger samples and a sufficient number of social network members in the ASD group (e.g., ASD adults who have children). Second, the cross-sectional nature of this study limits our ability to determine the causal relationship between physical contact and emotional bonding. Longitudinal studies are needed to investigate whether an increased touchable body area leads to stronger emotional bonds.

Third, we did not specify the type of social touch (e.g., stroking, patting, hugging) in this study. In the future, it is necessary to conduct studies examining relationship-specific preferences for different types of touch in individuals with ASD. Fourth, we did not record participant data on medical conditions, history of inappropriate touching, or skin-related factors that might affect touch allowance (e.g., psoriasis or eczema). This should also be addressed in future studies. Fifth, our study only involved touch allowance by other social network members, not by non-social objects (e.g., clothes). Thus, we could not determine whether reduced touch allowance in ASD is due to atypical tactile processing or is specific to social touch. Future studies should include non-social touch conditions in their questionnaires to address this question. Finally, the participants in the present study were limited to Japanese volunteers. Given that some cultural differences have been found in previous studies [29, 30], it would be worth investigating cross-cultural similarities among individuals with ASD.

Conclusion

We compared relation-specific bodily touch allowance maps, pleasantness of social touch, and emotional bonding with others between adults with ASD and TD adults. Our findings showed that social touch with most social network members was less acceptable to adults with ASD than to TD adults. However, we found that adults with ASD exhibited reduced emotional bonding only with specific members of their social network. Emotional bonding was more strongly dependent on the acceptability of social touch in the ASD group. These findings highlight the influence of autistic traits on the relationship between social touch and emotional bonding within social networks.

Abbreviations

AASP	Adolescent/Adult Sensory Profile
AQ	Autism-Spectrum Quotient
ASD	Autism spectrum disorder
FDR	False discovery rate
FSIQ	Full-Scale Intelligence Quotient
ROI	Region of interest
TAM	Touch area maps
TD	Typically developed control
TI	Touchability index

Supplementary Information

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Supplementary file1.

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Author contributions
Conceptualization: RK, HK, LN. Data collection: AF, KM, TM, NS, RK, HK. Formal analyses: AF, RK. Methodology: RK, LN. Software: RK. Visualization: RK. Writing: AF, RK. Funding acquisition: RK, HK. All authors read and approved the final manuscript.

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Availability of data and materials
The data that support the findings of this study are available on request from the corresponding author, RK. The data are not publicly available due to their containing information that could compromise the privacy of research participants.

Declarations

Ethics approval and consent to participate
The study protocol was approved by The Research Ethics Committee of University of Fukui (20210117), and the Research Ethics Committee at the Graduate School of Intercultural Studies, Kobe University (2021–2, 2022–4). All methods were carried out in accordance with the approved guidelines and the Declaration of Helsinki. Each participant in the main study provided written informed consent after receiving a detailed explanation of the study, and each participant in the pilot experiment provided online informed consent.

Competing interests
The authors declare no competing interests.

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