Atypical relationship-specific social touching and bonding in patients with autism spectrum disorder

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Abbreviated title: Relation-specific social touch of ASD

Abstract

Background: Autism spectrum disorder (ASD) is a neurodevelopmental disorder defined by social communication deficits, repetitive behaviors and restricted interests. Previous studies have reported aberrant sensory response of ASD and its implication with social touch. However, how atypical social touch is related to their social networks is not well understood. As in social grooming among monkeys, many species use touch to strengthen and manage their social networks. Recent research on typically developed (TD) human adults showed that the body locations where touch is allowed are associated with the strength of emotional bonds between the person touched and the toucher in culturally diverse samples. In the present study, we examined if autistic traits influence relationship-specific patterns of social touch and their relationship with emotional bonding in ASD.

Method: Seventy adults with ASD and 70 TD adults evaluated their emotional bonds with and the pleasantness of being touched by different members of their social networks (e.g., partner, father, friend, and stranger), then identified the regions of the body where touch was allowed. We hypothesized that the patterns of allowed interpersonal touch, as well as the effect of such tactile allowance on emotional bonding, would differ between ASD and TD.

Result: In both groups, strength of emotional bond was linearly associated with permissible touch area. In all social network members except for their children, nephews and female friends, ASD allowed less social touching than TD and reported social touching less pleasant. Linear regressions analyses showed a greater reliance of bodily touch allowance on emotional bonding for ASD than for TD.

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

Conclusions: Our results showed that adults with ASD do not prefer being touched in most social network members, while allowed interpersonal touch is more strongly associated with emotional

bonding in ASD. These results highlight the impact of autistic trait on the contribution of social touching to emotional connections among their social networks.

Keywords

Social touch, cultural differences, emotion, bonding

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, published by the American Psychiatric Association, 2013) [5].

Aberrant tactile processing is frequently reported in ASD [6, 7]. Interpersonal touch contributes to cognitive and socioemotional development in childhood [8, 9] and promotes the formation of social relationships as well as psychological and physical well-being in adulthood [10-12]. Studies have shown that individuals with ASD tend to avoid being touched by others [13-16]. A shortage of interpersonal touch is associated with anxiety, stress, depression, and feelings of loneliness [17-19], which are commonly observed in ASD population [20-23]. Thus, consistent with previous studies [24-28], atypical touch behaviors in ASD may be associated with their core symptoms.

One of the functions of social touch that has been attracting growing interest is its role in the formation of social structures by promoting affective relationships with others. Non-human primates dedicate a significant amount of time to grooming others, far exceeding the practical need to remove parasites or debris from their fur [29]. This social grooming plays a crucial role in forming social bonds, and the feeling of greater social closeness is reflected in increased prosocial behaviors [29, 30]. In female primates, grooming behavior is influenced by factors like attraction to dominant individuals, preference for kin, and competition for grooming partners [31-33], suggesting that differences in social touch patterns may be linked to variations in social structure.

In our previous research, we surveyed 1368 individuals from Western countries (Finland, France, Italy, Russia, and the UK) and 255 individuals from an Asian country (Japan), asking where on their bodies they would permit relatives, friends, and strangers to touch them [34, 35]. We also assessed the emotional bond between participants and touchers, as these bonds are key predictors of social contact and reflect individuals' positions within social networks [36, 37]. Regardless of the country, the topographic map of body areas that one was allowed to touch was associated with the strength of the emotional bond between the participant and the toucher. Thus, relationship-specific patterns of social touch seem to support the establishment and maintenance of social structures and affective relationships among humans beyond cultures [35]. Because atypical touch behaviors are associated with symptoms in ASD, we expected atypical relationship-specific patterns of social touch in ASD. Moreover, because individuals with ASD experience loneliness more frequently, emotional bonding of ASD with their social network members may be weaker than typically developed (TD) individuals. 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 TD adults and ASD adults. 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 the regions of the body where touch was allowed by each network member. We predicted that adults with ASD would report smaller touchable body area, reduced pleasantness from social touch, and weaker emotional bonding compared to those with TD. Moreover, we predicted that the effects of relationship-specific bodily maps on emotional bonding would differ between individuals with ASD and those with TD.

Materials and Methods

Participants

Seventy Japanese TD individuals and 70 individuals with ASD participated in the study (140 participants in total). 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. A preliminary online experiment confirmed that a sample size of 70 participants per group would be sufficient to replicate the relationship-specific touch allowances observed in previous studies [35]. 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 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-III (WAIS-III), IV(WAIS-IV) [38, 39] or short form of the WAIS-III [40]. 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 [41] to confirm autistic traits and the scores of Adult/Adolescent Sensory Profile (AASP) [42] to measure sensory processing profile in terms of low registration, sensation seeking, sensory sensitivity and sensation avoiding.

ASD group (main experiment)

Seventy individuals 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) [43]. Most of the participants in this group also had their ASD diagnosis confirmed by the Autism Diagnostic

Observation Schedule (ADOS-2, [44]). Some individuals with ASD had a history of comorbidity with attention deficit hyperactivity disorder (ADHD, n = 5), adjustment disorder (1), anxiety disorder (2), bipolar disorder (2), depression (9), epilepsy (2), idiopathic hypersomnia (1), and obsessive compulsive disorder (2).

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	104.1 ± 13.2	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; Adolescent/Adult Sensory Profile (AASP). FSIQ (Full Scale Intelligence Quotient) were calculated from WAIS-III short form, WAIS-III, and WAIS-IV. Age, AQ, AASP scores are shown as mean ± SD. T and p values are the results of independent-samples t-tests comparing TD and ASD (without family-wise error correction).

TD group (main experiment)

Seventy Japanese TD individuals [44 male, 30.0 ± 8.4 years (mean ± SD)] participated in the study at Kobe University and University of Fukui. The agency recruited TD participants whose mean age and sex ratio were matched with the ASD group (Table 1). No participant reported history of psychiatric disorders except for one individual (anxiety disorder).

Pilot online experiment

To estimate the sample size, 122 Japanese individuals (77 male, 31.3 ± 7.5 years [mean ± SD]) participated in the study via an online survey company (MyVoice Communications, Inc.). These individuals did not participate in the main experiment.

Data Acquisition

We developed the Japanese version of body painting tool (emBODY, [34, 35]) using an online experiment program (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 Inc.). The diameter of the painting tool was set to 11 pixels. Intellectual ability was assessed on a separate day from when this experiment was conducted.

We followed the same procedure as in our previous study [35]. 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). We also added ‘female stranger’ and ‘male stranger’ to the list 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 in their social network fitting one category (e.g. multiple brothers), they were instructed to pick one individual. The participants provided details regarding the sex (only for partners and children) and ages of the chosen social network members, along with approximations of the duration since their last encounter. We assumed that strangers were at around

participants' own age and the duration since the last encounter with them as 0 day (as almost everyone meets some unfamiliar individuals daily). In subsequent questions, the strangers were then referred to as 'a woman/man of your age whom you don't know.' Participants next rated their emotional bond with each network member on a scale ranging from 1 (indicating no emotional bond) to 10 (representing the strongest possible emotional bond) and provided estimates of their level of pleasantness regarding being touched by each member of their social network, using a scale from 1 (not pleasant at all) to 10 (extremely pleasant).

After 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 select the map they felt was most accurate. To check sustained attention on the task, we included a separate catch trial on which the participants were instructed to color both arms of the body outline. After answering completing the body mapping tool, the participants completed AQ and AASP.

Data Analysis

Data preprocessing

We used MATLAB (R2022b, Mathworks) and SPSS (version 27, IBM) for analyses. We first checked the data for completeness and confirmed that they performed the catch trial correctly. Data from the colouring 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 coloured images were binarized so that the amount of time a participant spent on colouring an area would not impact 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 2-D 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 by comparing pixelwise mean intensities using a two-tailed two-proportion z-test with alpha = 0.05, corrected for False Discovery Rate (FDR) [45]. The analysis was run separately for each body map (i.e. network member) with no correlation assumptions. To test the association between emotional bonds with network members and the corresponding touchable body areas, we first calculated a 'Touchability Index' (TI), defined as the proportion of coloured pixels within the body outline for each TAM, ranging from 0 to 1 [34, 35]. To quantify the differences in the topographies of acceptable touch, we also defined 8 anatomical Regions of Interest (ROIs) and calculated ROI-specific TIs as the proportion of coloured pixels within the ROI (arm, crotch/bottom, foot, hand, head, leg, shoulder, and torso). We then conducted multiple linear regression analysis, using the mean emotional bonds for each social network member as the dependent variable, with group (ASD and TD), sex, and mean TIs as explanatory variables. To confirm the result, we conducted additional analyses by using a summary statistics approach [46]. First, for each participant, we conducted a simple linear regression analysis on emotional bonds of social networks with TIs as exploratory variables (1st-level individual analysis). Subsequently, we conducted two-way ANOVA (group × sex) on parameter estimates of TIs that were obtained from the 1st-level individual analysis (2nd-level group analysis).

Results

Demographic data

Table 1 shows demographic data. AQ total score was significantly higher for ASD versus TD group [$t(138) = 14.31$, $p < 0.001$, Cohen's $d = 2.42$]. AASP scores were significantly higher for ASD than TD group in low registration, sensory sensitivity, sensation avoiding, while the score for sensation

seeking was greater for TD than ASD (p values < 0.001). Finally, touch rating for AASP was significantly greater for ASD [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 ASD and TD group (Supplementary Table 1). Two-sample t tests showed that the total number of social network members was significantly lower for ASD (9.39 ± 0.27, mean ± SEM) than TD participants (10.87 ± 0.27) [t(138) = 3.89, p < 0.001, Cohen's d = 0.66]. Two sample proportional z test showed that the ASD group had significantly lower number of partners [FDR-corrected p value (pFDR) < 0.001], children (pFDR = 0.01), and female and male friends (pFDR< 0.001) than TD group. Notably, the 15 TD participants and 3 ASD participants each had children.

TAMs for ASD and TD individuals

Figure 1ab 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 larger parts of the body than other members, and closest relatives were more likely permitted to touch over the head and shoulders. In contrast, adult strangers were restricted to touch only the hands. Direct comparison of TAMs between ASD and TD participants using two-proportion z-tests revealed that TD allowed more touching from all members except for child, nephew and female friends than did ASD (Figure 2 and Supplementary Figure 1). 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.

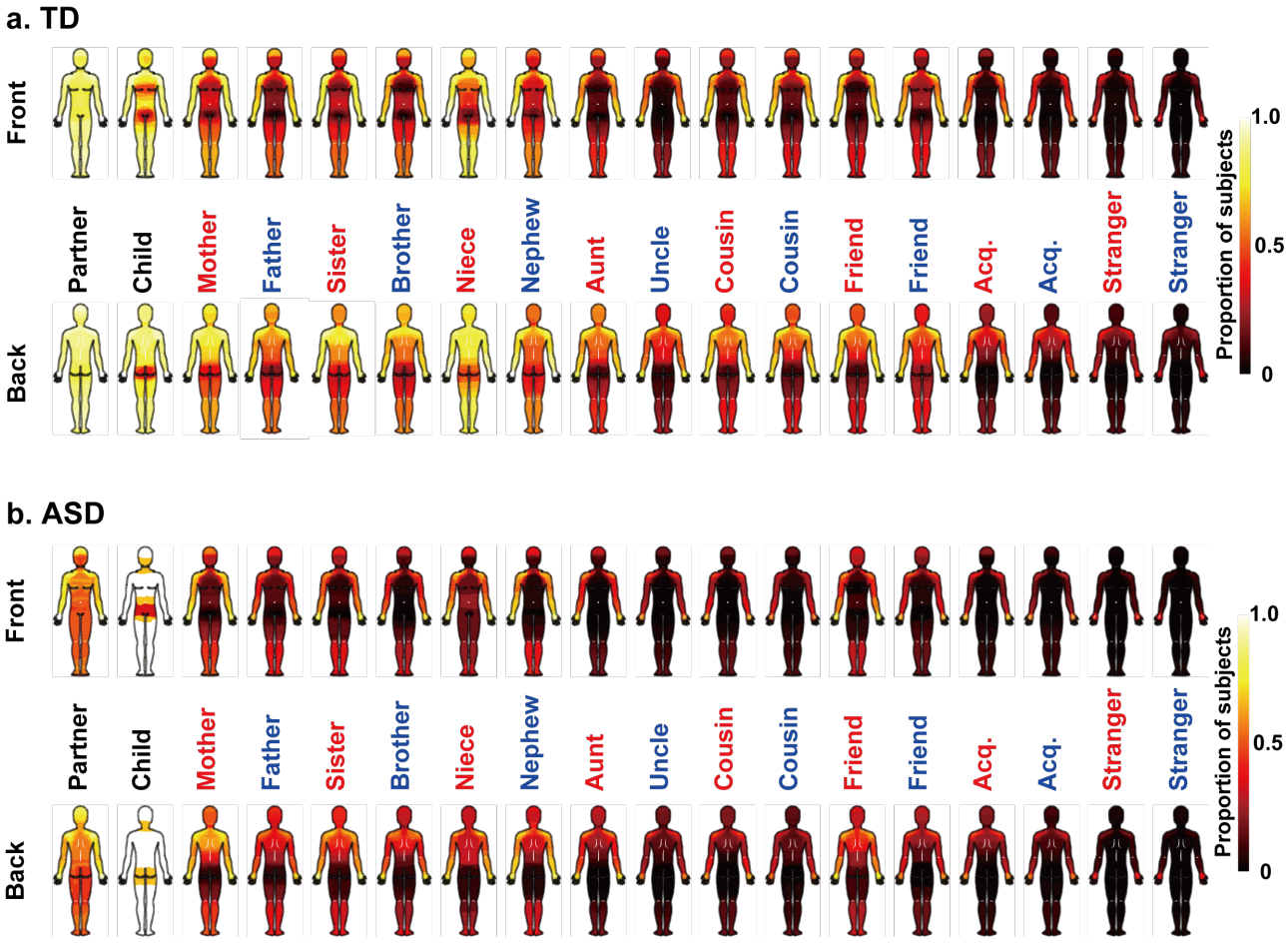

Figure 1. Relationship-specific TAMs in (a) TD and (b) ASD participants. The colouring displays the proportion of the sample reporting that being touched by each person in this area would be acceptable. Red and blue names indicate female and male network members, respectively; Acq. indicates acquaintances.

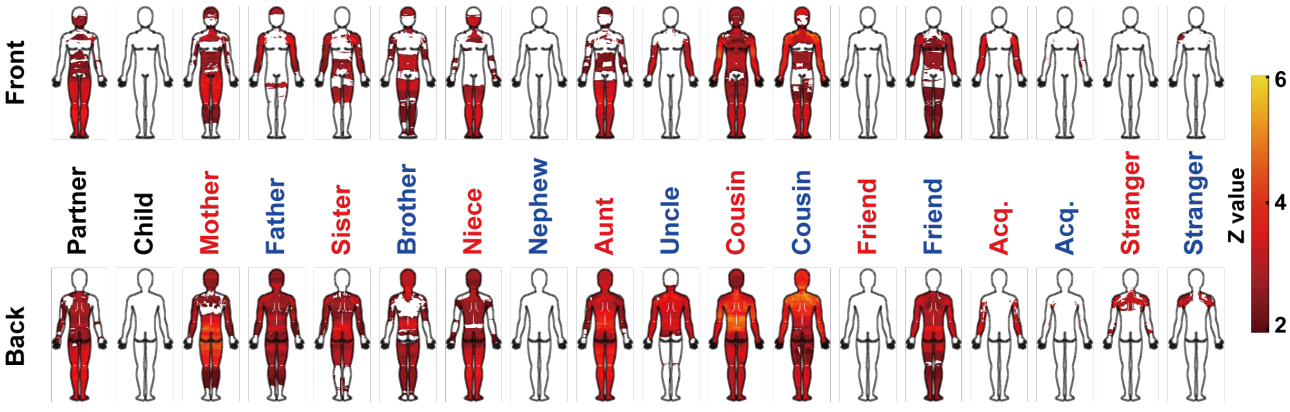

Figure 2. Statistical maps for the touch allowance differences (TD > ASD) between the groups. Red and blue names indicate female and male network members, respectively; Acq. indicates acquaintances. Red and yellow areas represent significantly higher touch allowance for TD participants, whereas the white 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 $p < 0.05$, FDR-corrected in each body map.

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. A Wilcoxon rank sum test (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, 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. The Wilcoxon rank sum test (with FDR correction) on pleasantness ratings revealed significantly greater pleasure for TD 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. The Wilcoxon rank sum test (with FDR correction) on TIs revealed a significantly greater TI in TD participants than in ASD participants for all network members except for children, female friends, and male strangers (pFDR < 0.05); the effect for female friends showed a trend toward significance (p = 0.066).

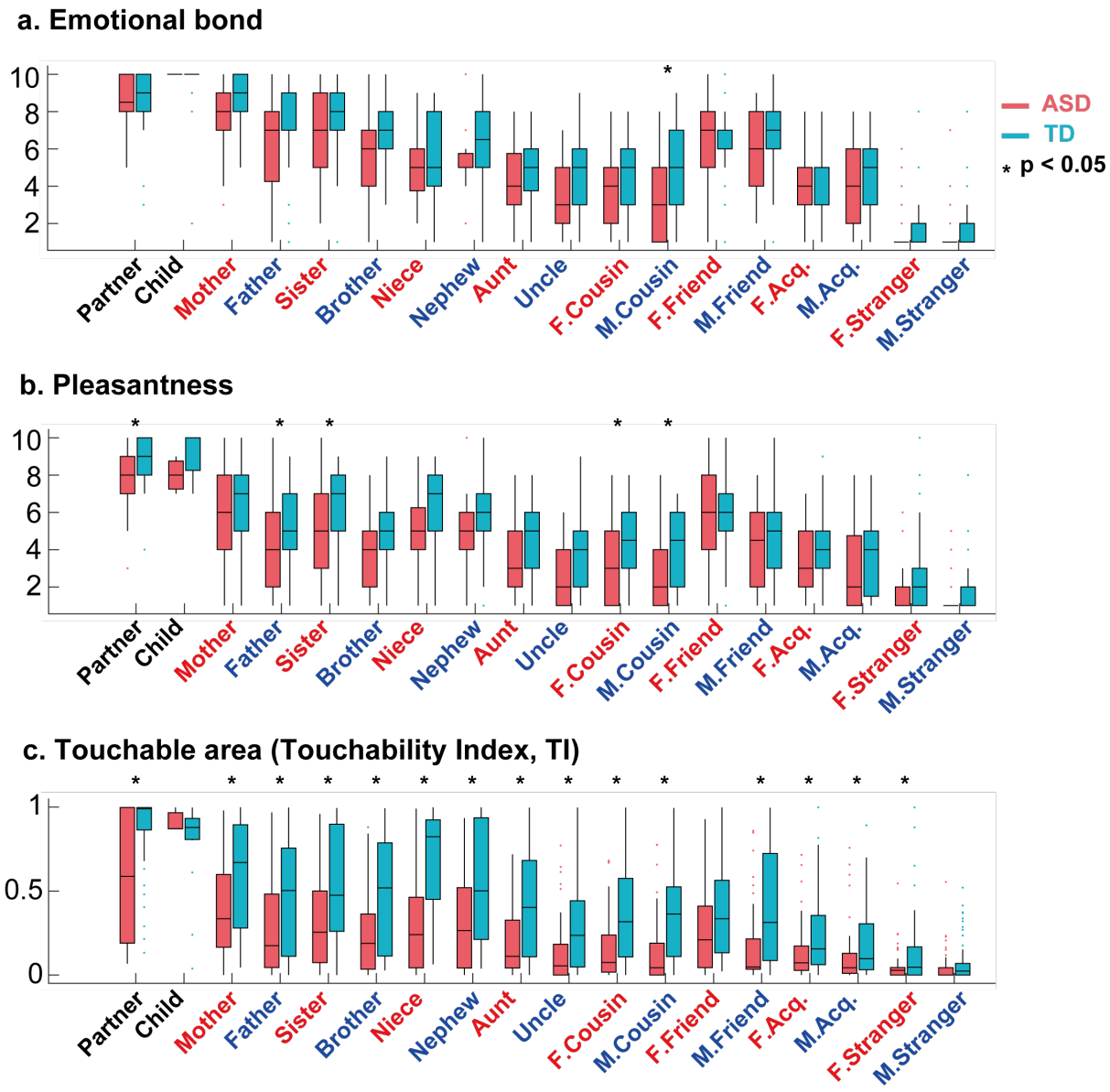

Figure 3. Boxplots of emotional bond (a), pleasantness (b), and touchability index (TI, c). Dots indicate outliers (the interquartile % range). TI ranges from 0 to 1. Asterisks indicate the significant results from Wilcoxon rank sum tests (with FDR correction over social network members). F. and M. indicate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

The relationship between emotional bond, pleasantness and TI

Figure 4 depicts the correlations between TI, pleasantness, and emotional bond. We excluded children from the plots because only three participants in the ASD group had children. We then conducted a linear regression analysis to predict mean emotional bond using mean TI, group and sex as explanatory variables. This revealed that altogether these variables explained 73% of the variance in emotional bonding (Adjusted $R^2 = 0.73$). Emotional bond was significantly predicted by TI [$\beta = 10.40$, $t(61) = 12.70$, $p < 0.001$] and TI × group interaction [$\beta = 2.13$, $t(61) = 2.70$, $p = 0.009$]. As a supplementary analysis, we conducted the same analysis with the summary statistics approach; we performed the linear regression analysis on emotional bond 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 sex) on these β values. This analysis confirmed a significantly greater slope for the ASD group compared to the TD group. We observed a significant main effect of group regardless of whether all members were included [$F(1, 136) = 7.04$, $p = 0.002$, $\eta_p^2 = 0.049$] or children were excluded [$F(1, 136) = 6.23$, $p = 0.014$, $\eta_p^2 = 0.044$]. No other effects were observed.

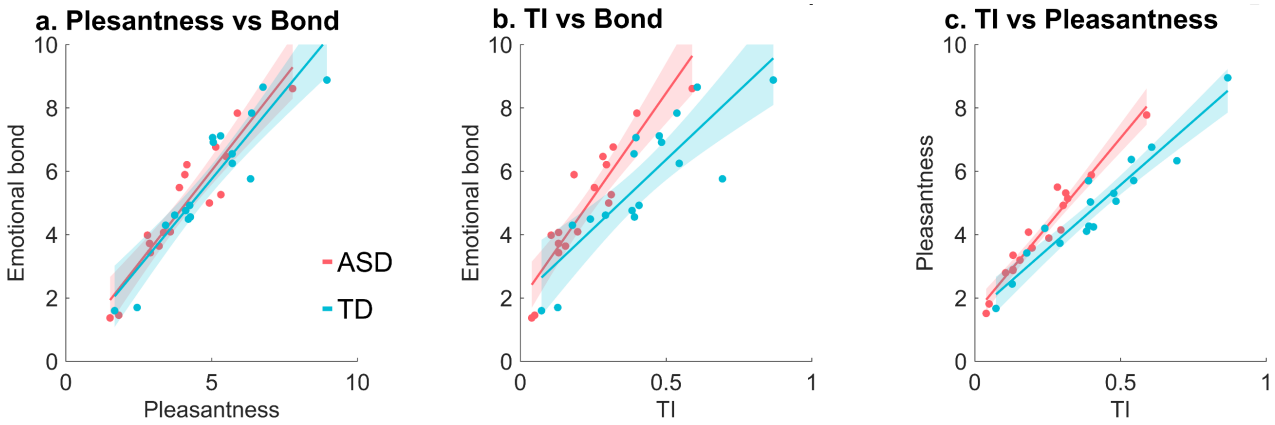

Figure 4. Correlations between touchable area, emotional bond and pleasantness. Each dot represents the average response for one member of the social network in each group (e.g. mother of TD participants), with a linear regression line and confidence interval for the regression fitted separately for each group. TI indicates Touchability Index, ranging from 0 to 1.

We next performed the 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 [$\beta = 9.40$, $t(61) = 21.27$, $p < 0.001$] and TI × group interaction [$\beta = 1.45$, $t(61) = 3.41$, $p = 0.001$] significantly predicted pleasantness. We again applied the linear regression analysis with TI as an explanatory variable to 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 sex) 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. Altogether the analysis showed that TI explained emotional bond and pleasantness differently between ASD and TD.

Sex differences

We next examined whether social network member sex influences touch acceptance similarly in TD and ASD. Figure 5 shows the relationship between touchable body area and the sex of the toucher with respect to male and female participants (blue and red dots) 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, the sex of the partner was determined by the participant's sex, making it difficult to compare the effect of sex on TI between the two groups. Additionally, because only a few ASD participants had children (2 female and 1 male), we excluded 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 sex was not significant ($p = 0.15$). We also observed a significant interaction between 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 for male touchers among female participants [$t(25) = 6.65$ $p < 0.001$, $d = 1.30$ for ASD; $t(25) = 9.22$ $p < 0.001$, $dz = 1.80$ for TD] but not in male participants (p values > 0.6).

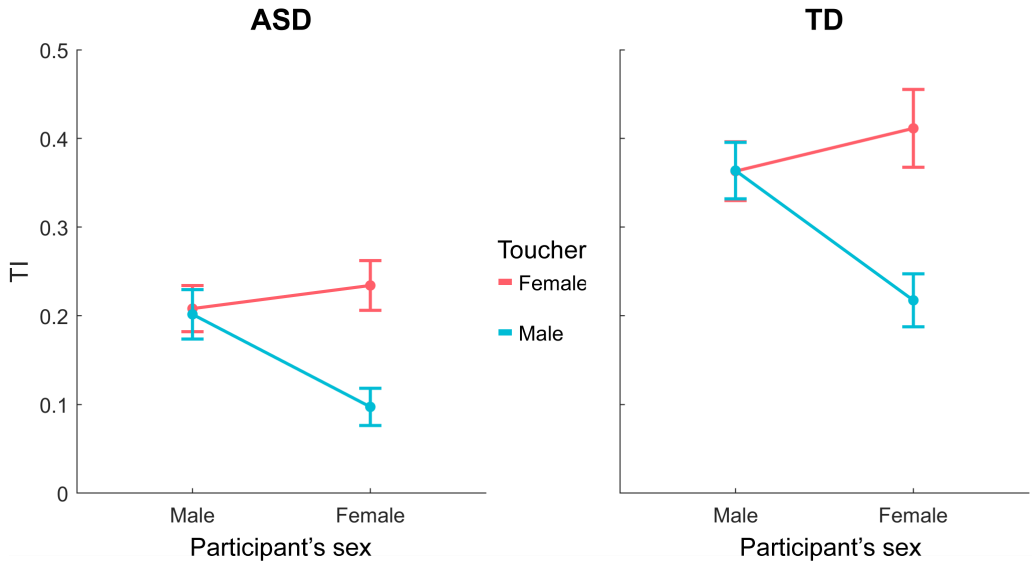

Figure 5. Sex difference.
Interaction plot of the average TI for male and female participants (blue and red dots, respectively) with respect to male and female touchers for each group (TD and ASD) are shown. Error bars depict SEM. Note: partners and children are excluded from the analyses, as the sex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

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 bond with regional TI, sex and group as the explanatory variable (Figure 6). We excluded children from the analysis due to few samples in ASD. This test showed significant effects of regional TI in all body areas (p values < 0.05). Moreover, this test showed significant interactions between TI and group in a few body parts, that is, greater rate of increase in bond as a TI (slope) for ASD than TD in the following body areas: foot [$\beta = 3.51$, $t(61) = 3.09$, $p = 0.003$], leg [$\beta = 4.59$, $t(61) = 4.43$, $p < 0.001$], crotch [$\beta = 3.03$, $t(61) = 2.06$, $p = 0.044$], torso [$\beta = 1.92$, $t(61) = 2.15$, $p = 0.036$],

and hand [β = 2.79, t(61) = 2.54, p = 0.014]. In all of these ROI, the emotional bond was more strongly dependent on changes in TIs (steeper slope) in the ASD sample. We also found three-way regional TI × sex × group interactions in foot [β = 2.42, t(61) = 3.30, p = 0.002] and leg [β = 1.59, t(61) = 2.25, p = 0.028].

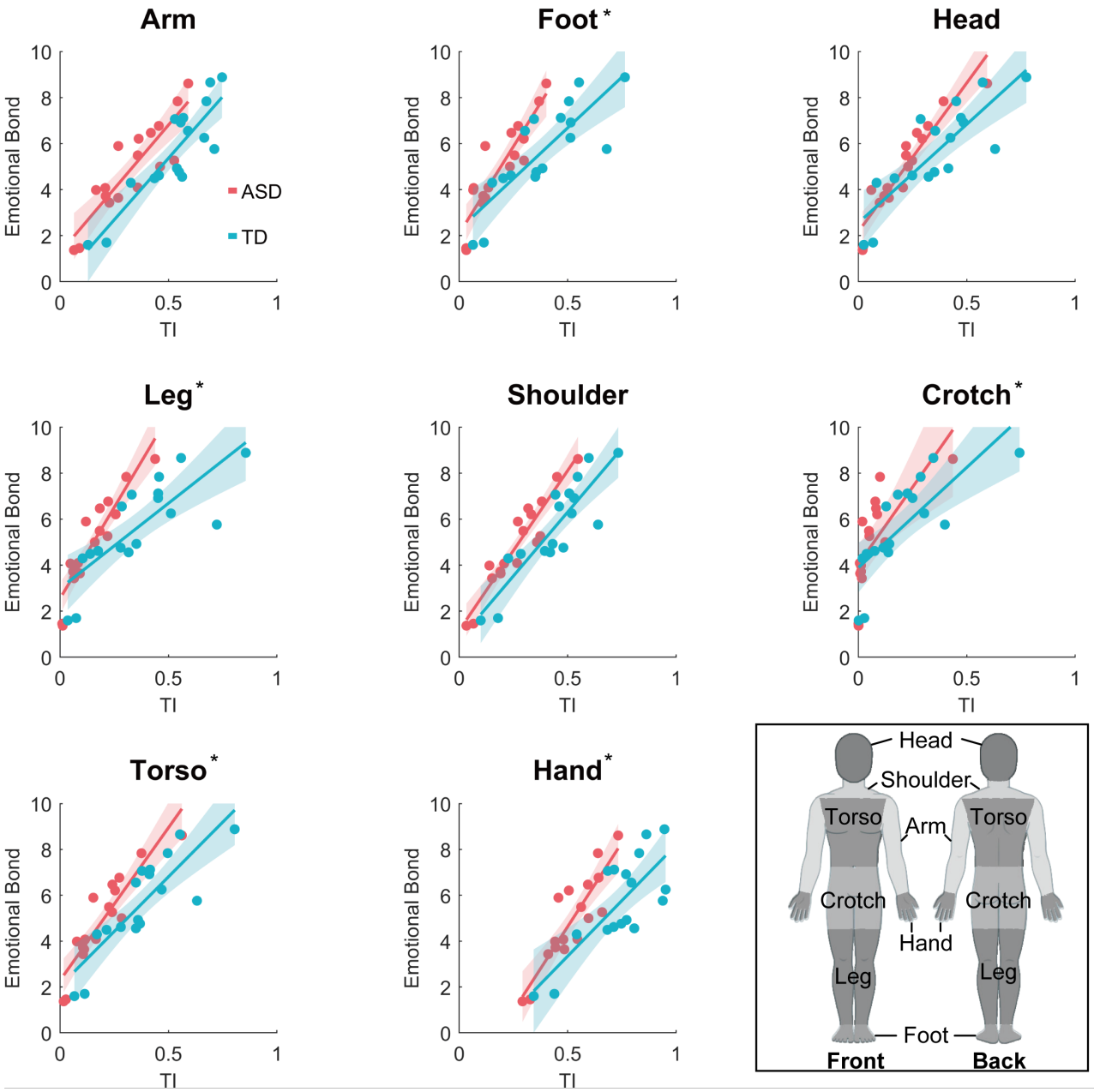

Figure 6. Regional group differences in the association between TI and emotional bond. Least-squares regression lines were fitted to each group separately. Each dot represents the average response for one member of the social network (e.g. 'ASD partner'). Asterisks indicate body areas showing significant interaction between TI and group.

To confirm the result, 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 in leg, crotch and torso, regardless of whether all members were included or children were excluded (p values < 0.05). Collectively, this complementary analysis confirmed that emotional bonding is more strongly related to TI in leg, crotch and torso for ASD than TD group.

Discussion

Our main findings are twofold. First, the body areas that different social network members were allowed to touch were significantly smaller for individuals with ASD compared to those with TD. Second, although the touchable area was linearly correlated with emotional bonding, this dependency of emotional bonds on the strength of touchable areas was greater in participants with ASD than those with TD.

Overall, participants with ASD allowed others to touch smaller areas of their bodies than TD participants in most cases involving social network members. The questionnaires based on Dunn's model of sensory processing [2] revealed higher sensory sensitivity and sensation-avoiding scores in participants with ASD compared to TD participants, partially aligning with previous findings [47-49]. These results suggest that the avoidance of social touch in ASD participants may be driven by heightened tactile sensitivity, irrespective of which social network member initiates the touch. Prior studies have shown that individuals with ASD tend to be defensive or avoid physical contact by others [15, 26, 47-48, 50]. We extended these findings by showing that, as compared to TD adults, ASD adults tend to allow less body areas to be touched, *largely independently of who would be touching them*. In other words, individuals with ASD are not only reluctant to be touched by strangers or distant family members, but also by those in the inner layers of their social network. These findings are consistent with prior research. For example, unlike TD adults, the electrodermal activity (EDA) of

ASD adults shows similar responses to both stroking (affective touch) and tapping (control), suggesting atypical sympathetic nervous activity in response to social touch in ASD [51]. Additionally, survey studies have indicated that adults with ASD have more negative attitudes toward social touch compared to TD adults [16, 50], with social touch often being described as unpleasant, and sometimes even painful or ticklish [16]. We also found that pleasure associated with social touching was lower for ASD than TD participants, even with close members of their social network (partners, fathers, sisters, and cousins). Thus, it is possible that atypical sensory processing in ASD makes social touch less pleasant, leading ASD participants to consider their body areas less touchable by others.

Sex differences in touchable areas were consistent between ASD and TD, though overall degree of touchable area was greater for TD than ASD. In both groups, female participants allowed women to touch greater amount of their body than men, whereas male participants did not show clear preference for touch by males versus females. This result in the TD sample replicates the previous finding on Japanese samples [35]. These similarities suggest that tactile allowance patterns may be relatively consistent between ASD and TD, despite overall differences in the extent of touchable areas.

The second main finding was that while emotional bonding was linearly dependent on the degree of touchable areas with social network members in both TD and ASD, touchable areas more strongly predicted emotional bonding in ASD adults compared to TD adults. This group difference in overall touchability was also observed in specific body regions, including the legs, torso, and crotch. These results suggest that although individuals with ASD generally prefer less physical contact than TD adults, the extent of such avoidance is strongly influenced by contextual factors, such as the emotional bond with the toucher.

Social touch often elicits positive emotions and is generally considered as a positive social signal [52-55]. For instance, subtle touch during social interactions leads people to form more favorable impressions of strangers [53, 55-57]. This strong link between touch and impression

formation indicates that touch may play a causal role in forming social bonds. Some research supports the idea that touch influences bonding in romantic relationships [58].

It is commonly reported that individuals with ASD tend to avoid being touched by others, while many ASD individuals anecdotally express a craving for touch. For example, Temple Grandin, a woman with ASD, remarked that 'Our bodies cry out for human contact, but when contact is made, we withdraw in pain and confusion' [59]. However, she 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, wrote, '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' [60]. Thus, once they allow others to touch themselves, they might experience pleasure of social touch, though its degree is not as strong as TD. Alternatively, emotionally close individuals may know how to touch ASD individuals without causing unpleasantness. Although the cross-sectional study cannot determine causal relationships between emotional bonding, pleasantness, and touchable areas, one may speculate that greater emotional bonding motivates ASD individuals to allow others to touch them. Collectively, atypical preference for social touch of ASD may lead to atypical interaction between social touch and emotional bonding.

In addition to our two main findings, we also found that ASD reported they had less partners, children, and friends. Our finding is consistent with previous findings that children and adolescents with ASD have fewer friends than their TD counterparts [61, 62]. For instance, children with ASD report lower levels of companionship, intimacy, and help compared to TD children [61] and often experience poorer quality and quantity of friendships [62]. Sensory avoidance, including aversion to social touch, may contribute to difficulties in forming social relationships. This avoidance might limit participation in social activities, particularly those involving physical contact, and lead to sensory

449 overload in social settings [63], potentially inhibiting the development of friendships and other social
450 bonds.

451 **Limitations**

452 Participants with ASD had less partners, children, and friends than TD participants. To minimize such
453 group difference on the analysis on the relationship between touchable body area and emotional
454 bonding, we conducted linear regression analyses both on the averaged group data, as well as
455 individual data and found similar results with both approaches. Thus, it is unlikely that such
456 differences lead to the group difference of linear relationships between emotional bonding and
457 touchable body area. This could however be addressed in future studies with larger samples and
458 sufficient number of social network members in the ASD group (e.g., ASD adults who have children).
459 Additionally, the cross-sectional nature of this study limits our ability to determine the causal
460 relationship between physical contact and emotional bonding. Longitudinal studies are needed to
461 investigate whether increased touchable body area leads to stronger emotional bonds. Lastly, we did
462 not specify the type of social touch (e.g., stroking, patting, hugging) in this study; future research
463 could explore relationship-specific preferences for different touch kinematics in ASD.

464

465 **Conclusion**

466 We compared relation-specific bodily touch allowance maps, pleasantness of social touch, and
467 emotional bonding with others between ASD and TD and found that individuals with social touch
468 was less acceptable for ASD versus TD group. However, acceptability of social touching was more
469 strongly dependent on emotional bonding in ASD. Because social touching is an important means for
470 establishing and maintaining social bonds [35], this aversion to social touching may lead to restricted
471 social networks and impoverished social relationships in ASD. Together, our results highlight the
472 impact of autistic trait on the relationship between social touch and emotional bonding within their
473 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

Declarations

Ethics approval and consent to participate

The study protocol was approved by The Research Ethics Committee of University of Fukui (20210117), and the local ethics committee at 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. Written informed consent was obtained from each participant after receiving a detailed explanation of the study for the main experiment and online informed consent was obtained for pilot experiment on TD subjects.

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.

Competing interests

The authors declare that they have no competing interests.

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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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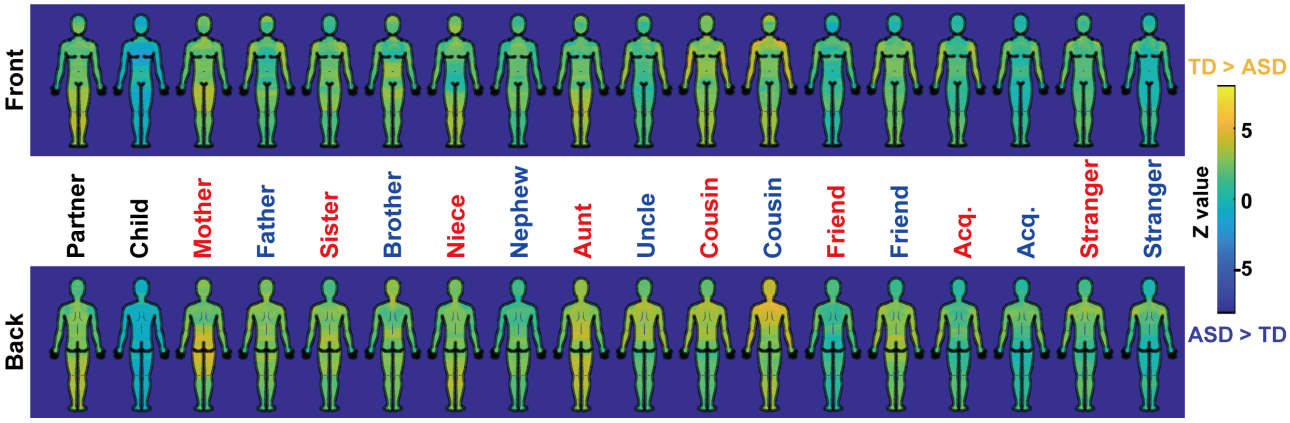
Supplementary Figure 1



Supplementary Figure 1. Unthresholded statistical maps for the touch allowance differences between the groups. Red and blue names indicate female and male network members, respectively; Acq. indicates acquaintances. The data are presented without any statistical threshold. See Figure 2 for thresholded statistical maps.

Supplementary Table 1 Numbers of social network members

	ASD			TD			Two proportional z test	
	Male	Female	Total	Male	Female	Total	Z value	pFDR
Partner	8	10	18	23	19	42	-4.10	<0.001
Child	1	2	3	10	5	15	-3.03	0.01
Mother	44	23	67	42	25	67	0	1
Father	41	26	67	35	24	59	2.25	0.08
Sister	24	19	43	29	14	43	0	1
Brother	25	12	37	20	16	36	0.169	1
Niece	10	3	13	14	7	21	-1.58	0.26
Nephew	14	5	19	15	9	24	-0.92	0.65
Aunt	37	18	55	34	19	53	0.40	1
Uncle	36	18	54	34	18	52	0.39	1
Female Cousin	37	24	61	32	20	52	1.93	0.13
Male Cousin	39	19	58	30	16	46	2.32	0.08
Female Friend	10	20	30	41	26	67	-6.78	<0.001
Male Friend	25	13	38	43	20	63	-4.71	<0.001
Female Acq	31	26	57	40	25	65	-2.02	0.12
Male Acq	40	19	59	41	23	64	-1.29	0.39

pFDR, p values FDR adjusted for multiple comparisons over social network members (16).

Supplementary Table 2 Emotional bond, pleasantness, and touchability index (TI)

Social network	Emotional Bond			Pleasantness			Touchability Index (TI)		
	ASD	TD	pFDR	ASD	TD	pFDR	ASD	TD	pFDR
Partner	8.61 ± 0.33	8.88 ± 0.24	0.4489	7.78 ± 0.45	8.95 ± 0.19	0.0423	0.59 ± 0.09	0.87 ± 0.04	0.0356
Child	10.00 ± 0	9.27 ± 0.54	1	8.00 ± 0.58	9.27 ± 0.3	0.1265	0.91 ± 0.04	0.78 ± 0.07	0.4975
Mother	7.84 ± 0.23	8.66 ± 0.17	0.0591	5.88 ± 0.31	6.76 ± 0.25	0.0738	0.40 ± 0.03	0.61 ± 0.04	0.0008
Father	6.21 ± 0.32	7.12 ± 0.29	0.0626	4.15 ± 0.32	5.31 ± 0.29	0.0423	0.30 ± 0.04	0.48 ± 0.04	0.0037
Sister	6.77 ± 0.36	7.84 ± 0.27	0.0626	5.14 ± 0.41	6.37 ± 0.3	0.0423	0.32 ± 0.04	0.54 ± 0.05	0.0037
Brother	5.49 ± 0.39	6.92 ± 0.31	0.0591	3.89 ± 0.36	5.06 ± 0.31	0.0738	0.25 ± 0.04	0.48 ± 0.06	0.0037
Niece	5.00 ± 0.51	5.76 ± 0.47	0.4501	4.92 ± 0.61	6.33 ± 0.45	0.0886	0.30 ± 0.08	0.69 ± 0.06	0.0037
Nephew	5.26 ± 0.35	6.25 ± 0.45	0.0626	5.32 ± 0.59	5.71 ± 0.44	0.2817	0.31 ± 0.06	0.54 ± 0.07	0.0365
Aunt	4.09 ± 0.27	4.92 ± 0.27	0.0626	3.58 ± 0.27	4.25 ± 0.27	0.1154	0.20 ± 0.03	0.41 ± 0.04	0.0008
Uncle	3.72 ± 0.26	4.62 ± 0.29	0.0626	2.87 ± 0.24	3.73 ± 0.29	0.0738	0.13 ± 0.02	0.29 ± 0.04	0.001
Female Cousin	3.64 ± 0.27	4.56 ± 0.28	0.0591	3.20 ± 0.24	4.27 ± 0.26	0.0365	0.15 ± 0.02	0.39 ± 0.04	0.0001
Male Cousin	3.43 ± 0.30	4.76 ± 0.30	0.0403	2.90 ± 0.27	4.11 ± 0.28	0.0229	0.13 ± 0.03	0.38 ± 0.04	0
Female Friend	6.47 ± 0.39	6.55 ± 0.20	0.9345	5.50 ± 0.44	5.70 ± 0.23	0.8774	0.28 ± 0.05	0.39 ± 0.04	0.0657
Male Friend	5.89 ± 0.33	7.06 ± 0.22	0.0555	4.08 ± 0.36	5.03 ± 0.26	0.0886	0.18 ± 0.04	0.4 ± 0.04	0.0008
Female Acquaintance	4.07 ± 0.25	4.49 ± 0.23	0.4489	3.35 ± 0.26	4.20 ± 0.24	0.0705	0.13 ± 0.02	0.24 ± 0.03	0.0031
Male Acquaintance	3.98 ± 0.27	4.30 ± 0.25	0.4845	2.80 ± 0.25	3.42 ± 0.24	0.1154	0.11 ± 0.02	0.18 ± 0.02	0.0356
Female stranger	1.46 ± 0.13	1.70 ± 0.15	0.0626	1.81 ± 0.15	2.44 ± 0.23	0.0853	0.05 ± 0.01	0.13 ± 0.02	0.0044
Male stranger	1.37 ± 0.12	1.60 ± 0.15	0.2116	1.51 ± 0.13	1.67 ± 0.16	0.2874	0.04 ± 0.01	0.07 ± 0.01	0.0882

Each value is shown in mean ± SEM