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Article

Keywords:

Posted Date: November 11th, 2026

DOI: https://doi.org/10.21203/rs.3.rs-10758256/v1

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Additional Declarations: There is **NO** Competing Interest.

Altered social touch interpretation in autism is specific to somatosensory experience

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Abstract (<150 words)

Tactile experiences are central to social communication and relationship formation, yet are often altered in autism spectrum conditions (ASC). We investigated whether ASC is associated with differences in the interpretation and affective evaluation of social touch. ASC participants (*n* = 117) and neurotypical controls (*n* = 117) either directly experienced or observed standardized social touch gestures representing interpersonal interactions. Autistic traits were associated with altered interpretation of social meaning during tactile experience, but not observation, and with lower pleasantness ratings in both conditions, particularly for felt touch. Comparisons between ASC and control participants mirrored these findings. In the viewed-touch experiment, open-ended responses closely matched forced-choice results, indicating that interpretations were robust to response format. Together, these findings suggest that autism is associated with alterations in social and affective touch processing, with the strongest effects occurring during direct tactile experience.

Introduction

Touch provides profound physical and mental health benefits[1] while also serving as a powerful means of communication, influencing social behaviors such as cooperation, dominance, and emotional bonding[2,3]. It bridges and differentiates our sense of self from others[4–6]. Through touch, humans can experience and convey a wide palette of emotions, sensations, and intentions[7–9]. Touch is therefore a powerful non-verbal tool for social functioning, carrying both interpersonal meaning and affective value[9,10]. Despite its importance for social communication, relatively little is known about how individual differences shape the affective and social interpretation of interpersonal touch, or whether such differences arise from tactile experience itself or from the broader interpretation of social interactions.

Autism Spectrum Condition (ASC) is a neurodevelopmental condition characterized by alterations in social interaction[11,12]. Autistic characteristics vary dimensionally and extend continuously into the general population[13]. ASC is also associated with altered tactile perception. Individuals with ASC exhibit altered sensitivities to somatosensory stimuli, including differences in tactile detection and discrimination[14–16], and tend to rate affective and interpersonal touch, as less pleasant or more aversive than controls[17–20]. Altered touch sensitivity is linked to reduced social functioning and difficulties in non-verbal communication[16,21,22]. Yet, relatively little is known about how autistic traits influence the perception of interpersonal touch as a form of social communication. In particular, it remains unclear whether differences in social touch processing reflect altered affective and

discriminative responses to direct tactile experience, differences in the interpretation of social interactions more generally, or both.

Autism-related tactile differences can manifest at multiple levels of processing, from sensory encoding to affective and social evaluation, however, their underlying mechanisms remain unresolved. Brain imaging studies report altered responses to touch in ASC in regions implicated in sensory and social-affective processing, including the somatosensory cortex, insula, and superior temporal sulcus[23–26], although findings have not been entirely consistent[27]. Similarly, electrophysiological studies identify altered neural responses to gentle touch in ASC[28]. However, such findings do not readily distinguish whether atypical responses arise from altered tactile experience itself or from broader differences in attention, affective evaluation, or social cognition[29].

In the general population, vicarious touch experienced via watching videos of pleasant touch show cortical processing similar to actual touch[30]. However, a video-based functional brain imaging study found that autistic adults did not show the somatosensory representations of observed socio-affective touch seen in NTs[31], suggesting that the similar processing for felt and viewed touch may not generalize to autistic individuals. Together, these findings motivate a comparison of responses to felt and viewed social touch in relation to autistic traits, in order to determine whether observed differences are specific to somatosensory experience or reflect more general differences in social touch processing.

Here we compared felt and viewed touch to evaluate the somatosensory-specific contribution to social touch in autism. To investigate social touch experimentally, stimuli must retain the social meaning of natural interpersonal interactions while remaining sufficiently standardized for controlled testing. We have previously captured a variety of different interpersonal touch interactions under naturalistic conditions and found that successful strategies for touch communication share common features. These features were used to develop standardized touch expressions, based on the most successful touch strategies used intuitively between pairs of people in a close relationship to communicate happiness, sadness, love, gratitude, (getting) attention, and calming. Naïve participants were able to interpret these expressions when delivered by trained experimenters, with a level of recognition similar to intuitive touch between pairs in a close relationship[9]. Using microneurography and motion tracking, we also characterized the peripheral neural signals elicited by these standardized touch expressions[32]. The results demonstrated that information about both gesture identity and affective valence is available in peripheral tactile afferent activity, supporting the idea that social touch can convey rich interpersonal information through direct somatosensory input.

Using the previously developed standardized expressions[9], we evaluated both touch message agreement, defined as the correspondence between the intended message of a touch expression and the participant's interpretation, and perceived pleasantness of the expression. A key feature of our approach was to present the same expressions in two independent experiments: as felt touch, delivered to the forearm by a trained experimenter, or as viewed touch, presented in short video clips. This contrast provided a neurobiologically informative way to ask whether associations with autistic traits reflected differences in the general interpretation of touch expressions or were more specifically tied to the direct somatosensory input through which the intended messages were felt. We hypothesized that if autistic traits are primarily associated with altered somatosensory processing, associations should be stronger for felt than viewed touch. Conversely, if differences reflect broader social-cognitive processing, comparable effects should be observed across both modalities.

Results

The interpretation of social meaning and affective evaluation of a previously validated set of standardized social touch gestures[9] were examined in two experiments. Participants either directly experienced the touch expressions (Experiment 1, felt-touch) or observed video recordings of the same expressions (Experiment 2, viewed-touch). The expressions were intended to communicate attention, love, happiness, sadness, calming, and gratitude. In both experiments, participants judged what social message each touch expression was intended to communicate and rated its pleasantness. In order to validate the results across response formats, the viewed-touch experiment included two groups that differed in how they made their responses. One group used the same forced-choice response paradigm as in the felt-touch experiment selecting an option from a list, while the other answered in free-text boxes.

Participant characteristics across felt- and viewed-touch experiments

We first compared participant characteristics across experiments and between the ASC and control groups. Although the ASC group was consistently younger than the control group, the magnitude of this age difference was similar across the felt-touch, viewed-touch forced-choice, and viewed-touch open-ended experiments (**Table 1 and Supplementary Fig. 1a**). The ASC group also scored higher than the control group on the Autism-Spectrum Quotient (AQ), Broad Autism Phenotype Questionnaire (BAPQ), Social Touch Questionnaire (STQ), and Toronto Alexithymia Scale (TAS) across all experiments (**Table 1 and Supplementary Fig. 1b**).

Table 1 Participant characteristics across experiments.

	Experiment 1 Felt-touch		Experiment 2 Viewed-touch			
	forced-choice		forced-choice		open-ended	
	ASC	Control	ASC	Control	ASC	Control
n	34	34	46	46	37	37
Age, mean	21.1 ± 4.8	24.9 ± 5.7	22.4 ± 3.0	24.7 ± 5.3	23.0 ± 2.7	25.1 ± 4.6
AQ score	30.2 ± 8.9	12.9 ± 6.1	32.8 ± 7.7	18.1 ± 8.4	34.3 ± 7.9	19.4 ± 7.3
Female/male/other	19/14/1	20/14/0	28/17/1	27/18/1	18/18/1	21/16/0

Age and AQ scores are presented as mean ± s.d.; all other values are counts. AQ, Autism-Spectrum Quotient; ASC, autism spectrum condition.

Autistic traits influence the interpretation of felt but not viewed touch

In the touch communication task, participants selected the message they thought each touch expression was intended to communicate. Overall touch message agreement between the selected and intended messages across the six expressions was quantified using $F1_{micro}$. Across participants from both groups, higher AQ scores were associated with lower touch message agreement when participants were touched. By contrast, touch message agreement was not significantly associated with AQ scores when participants viewed touch (**Fig. 1a**).

Autistic traits are related to lower pleasantness ratings for felt and viewed touch

In the touch pleasantness rating task, participants rated the pleasantness of each touch expression on a visual analog scale (VAS). Across participants from both groups, higher AQ scores were associated with lower perceived pleasantness both when participants were touched and when they

viewed touch (**Fig. 1b**). Lower pleasantness was also associated with less positive attitudes towards social touch (higher STQ scores) in both experiments and with higher TAS scores when participants viewed touch. Higher AQ scores were also associated with higher STQ scores in both experiments (**Fig. 1c**).

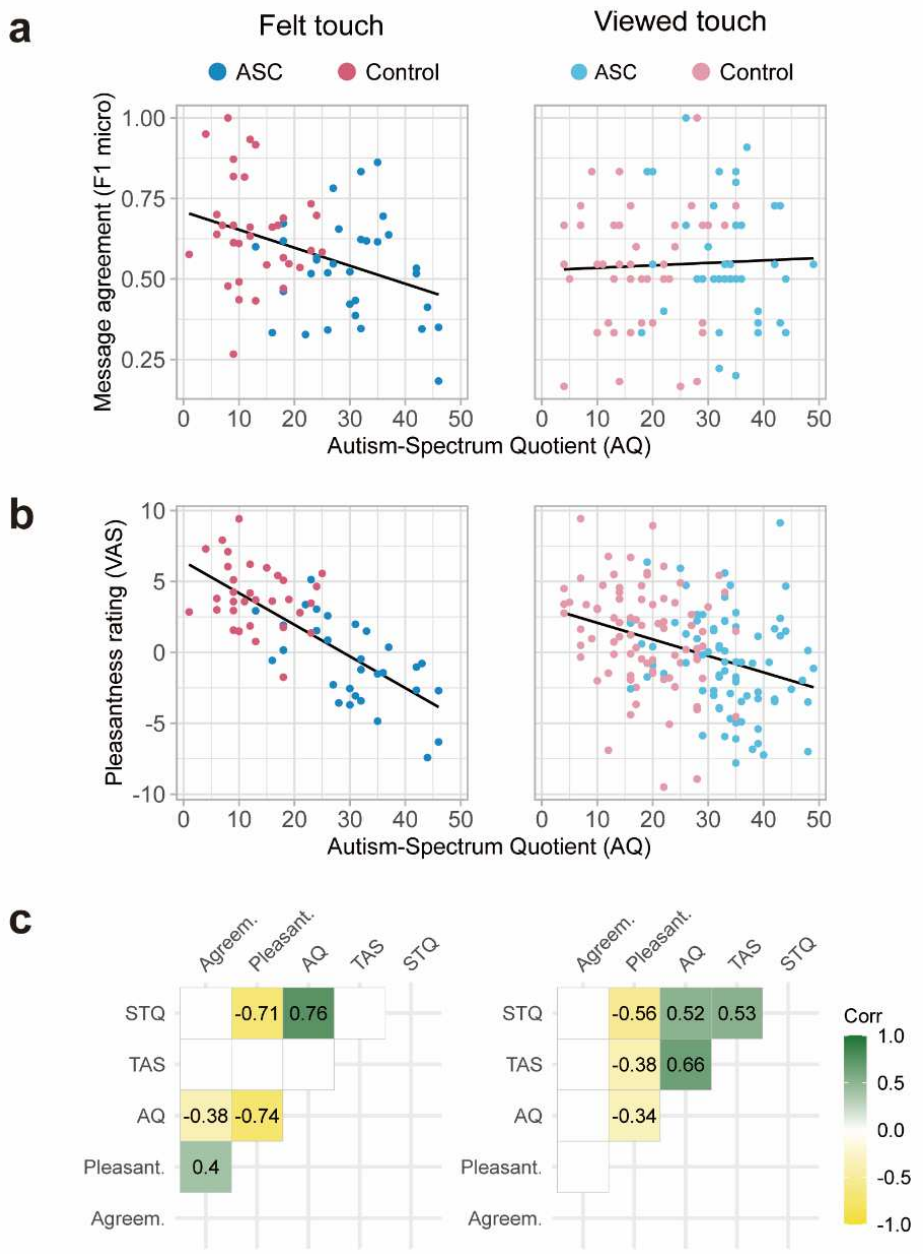


Figure 1 Individual traits in interpretation and perceived pleasantness of social touch.
Participants either felt or viewed six standardized touch expressions, and completed separate touch communication and touch pleasantness rating tasks. Blue and pink points denote ASC and control participants, respectively. Black lines show linear fits across ASC and control participants within each experiment. **a**, Associations between Autism-Spectrum Quotient (AQ) scores and overall touch message agreement, quantified for each participant using $F1_{micro}$ across the six expressions. Higher AQ scores were associated with lower agreement in the felt-touch experiment (r = −0.38, 95% CI [−0.62, −0.06], p = 0.012; ASC, n = 34; control, n = 34), but not in the viewed-touch experiment (r = 0.05, [−0.21, 0.29], p = 1.00; ASC, n = 45; control, n = 46). **b**, Associations between AQ scores and perceived pleasantness, calculated as each participant's mean pleasantness rating across the six expressions. Higher AQ scores were associated with lower pleasantness in both the felt-touch experiment (r = -0.74, [-0.86, -0.53], p < 0.001; ASC, n = 34; control, n = 34) and the viewed-touch experiment (r = -0.34, [-0.51, -0.16], p < 0.001; ASC, n = 82; control, n = 83). **c**, Pearson correlation matrices for touch message agreement (Agreem.), perceived pleasantness (Pleasant.), AQ, Toronto Alexithymia Scale (TAS) scores and Social Touch Questionnaire (STQ) scores. Correlation coefficients are indicated inside the squares and by color. Blank white squares indicate

correlations that did not reach statistical significance, with family-wise alpha = 0.05 using Holm-Bonferroni correction for multiple comparisons.

Group differences in message agreement for specific expression in felt, but not viewed touch

We next examined group differences in overall and expression-specific touch message agreement for felt and viewed touch. In addition to overall agreement across the six expressions ($F1_{micro}$), agreement for each expression was quantified separately using F1. For felt touch, overall message agreement was higher in the control group than in the ASC group (Control: $F1_{micro}$ = 0.66, 95% CI [0.64, 0.68]; ASC: $F1_{micro}$ = 0.53, 95% CI [0.51, 0.55]; nonparametric bootstrapped CIs do not overlap). At the expression level, agreement exceeded the chance level for all six touch expressions in both groups, but was lower in the ASC group for "attention", "love", and "happiness" (**Fig. 2a**). The confusion matrices show that ASC participants more frequently interpreted "love" and "happiness" as "calming", "attention", or "other" (**Fig. 2b**).

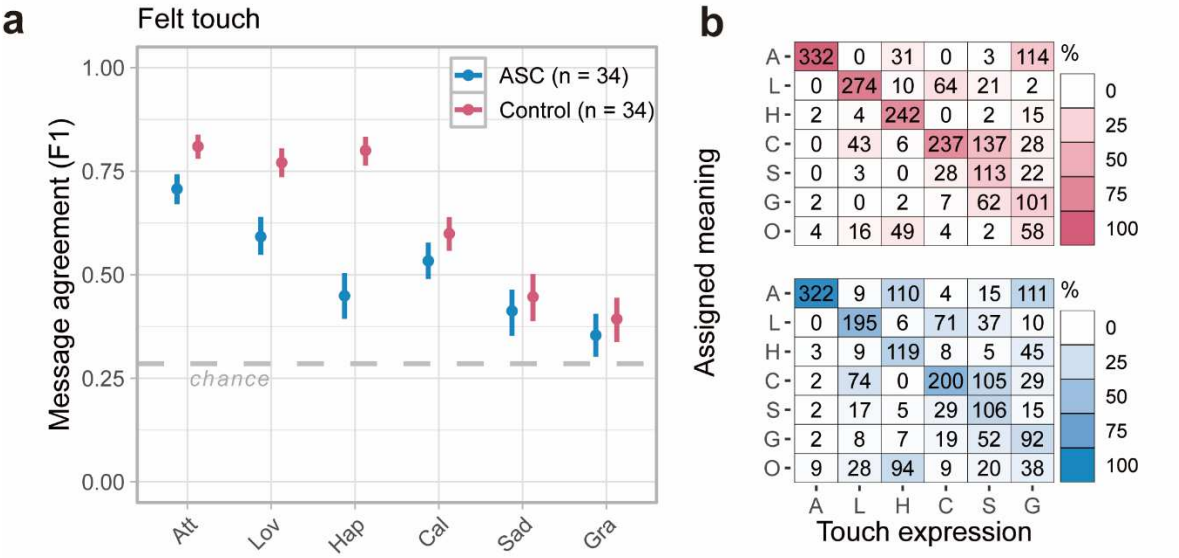


Figure 2 Touch message agreement for felt-touch expressions.
a, Touch message agreement for each expression, quantified using F1, with 95% bootstrap confidence intervals. The control group had significantly higher agreement scores than the ASC group for attention (control, 95% CI [0.78, 0.84]; ASC, [0.67, 0.74]), love (control, [0.74, 0.81]; ASC, [0.55, 0.64]), and happiness (control, [0.76, 0.83]; ASC, [0.39, 0.50]), as indicated by non-overlapping confidence intervals. **b**, Group-level confusion matrix for the control (pink) and ASC group (blue). Numbers inside the squares indicate trials pooled across participants, and shading indicates the percentage of responses assigned to each selected message for each intended expression. ASC, *n* = 34; control, *n* = 34. Blue and pink denote ASC and control participants, respectively. Touch expressions and labels are abbreviated: Att/A (Attention), Lov/L (Love), Hap/H (Happiness), Cal/C (Calming), Sad/S (Sadness), Gra/G (Gratitude).

By contrast, for viewed touch, no clear group difference was evident in overall message agreement in the forced-choice task (control: $F1_{micro}$ = 0.53, 95% CI [0.47, 0.59]; ASC: $F1_{micro}$ = 0.56, 95% CI [0.50, 0.62]). At the expression level, agreement exceeded the chance level for "attention", "love", "happiness", and "calming" in both groups, with no clear group differences across expressions (**Fig. 3a,b**).

Open ended responses are comparable to forced choices

In addition, to examine whether the absence of group differences observed for viewed touch depended on predefined response options, a separate group of participants provided open-ended descriptions of the touch expressions. These responses were analysed by human evaluators and a large language model (LLM). Three human evaluators independently assigned each response to one of the six intended-message labels or to “other”, and GPT-4o performed the same classification. Neither approach revealed clear group differences (**Fig. 3c,d**). GPT-4o classified responses to “happiness” as “other” more often than human evaluators, largely because descriptions of “playfulness” were not assigned to the “happiness” label.

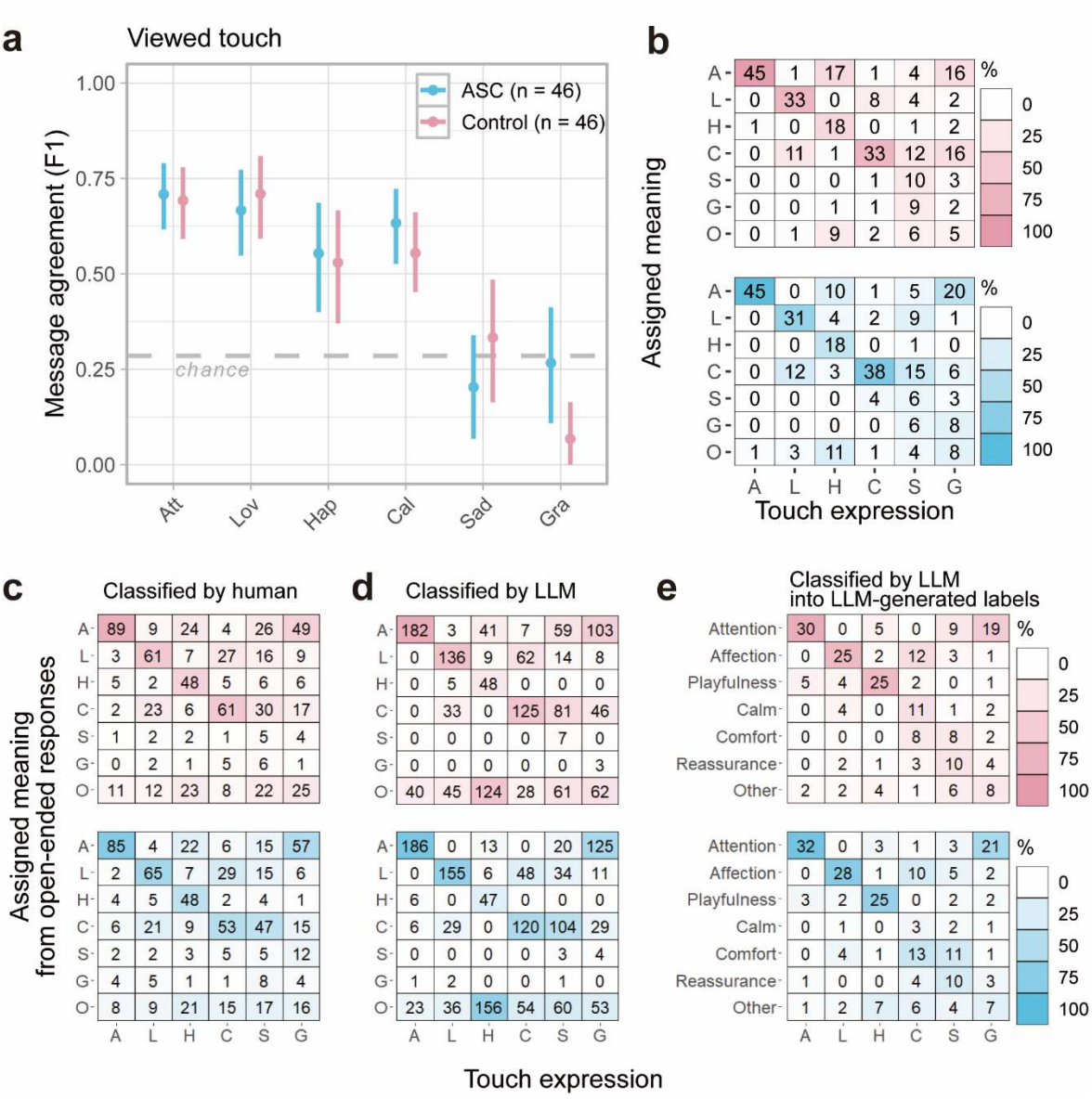


Figure 3 Touch message agreement and open-ended interpretations of viewed-touch expressions.
a,**b**, Forced-choice responses (ASC, *n* = 46; control, *n* = 46). **a**, Touch message agreement for each expression, quantified using F1, with 95% bootstrap confidence intervals. No clear group differences were evident across expressions. Agreement exceeded the chance level for attention, love, happiness, and calming in both groups. **b**, Group-level confusion matrix. **c-e**, Open-ended responses (ASC, *n* = 37; control, *n* = 37). Responses were categorized by **c**, three human evaluators using the six intended-message categories and 'other'; **d**, GPT-4o (OpenAI) across six repetitions using the same categories; and **e**, GPT-4o using six response-derived categories without being provided with the intended-message categories**.** In **b-e**, numbers inside the squares indicate pooled classification counts, and shading indicates the percentage of responses within

each intended expression. Blue and pink denote ASC and control participants, respectively. Touch expressions and labels are abbreviated: Att/A (Attention), Lov/L (Love), Hap/H (Happiness), Cal/C (Calming), Sad/S (Sadness), Gra/G (Gratitude).

To characterize participants' interpretations without imposing the intended-message labels, GPT-4o was next used to derive categories directly from the open-ended responses. The resulting categories were "attention," "affection," "playfulness," "calm," " comfort," and " reassurance" (**Fig. 3e**). These categories broadly matched the labelled-response structure for "attention", "love", "happiness" and "calming", with "love" corresponding to "affection" and "happiness" corresponding to "playfulness", whereas "sadness" and "gratitude" did not emerge as distinct dominant categories. No clear group differences were evident in the distributions of these response-derived categories. Thus, the shared interpretation of viewed touch was not limited to the forced-choice format.

ASC group reports lower pleasantness across modalities and expressions

The ASC group rated felt touch expressions as less pleasant overall than the control group (control: rating = 4.02, 95% CI [3.28, 4.75]; ASC: rating = -0.53, 95% CI [-1.28, 0.22]). This group difference was consistent with the expression-level ratings, which showed lower pleasantness in the ASC group for all felt touch expressions except attention (**Fig. 4a**). The ASC group also rated viewed touch expressions as less pleasant overall than the control group (control: rating = 1.09, 95% CI [0.63, 1.56]; ASC: rating = -0.63, 95% CI [-1.10, -0.17]). At the expression level for viewed touch, lower pleasantness ratings in the ASC group were observed for calming (**Fig. 4b**).

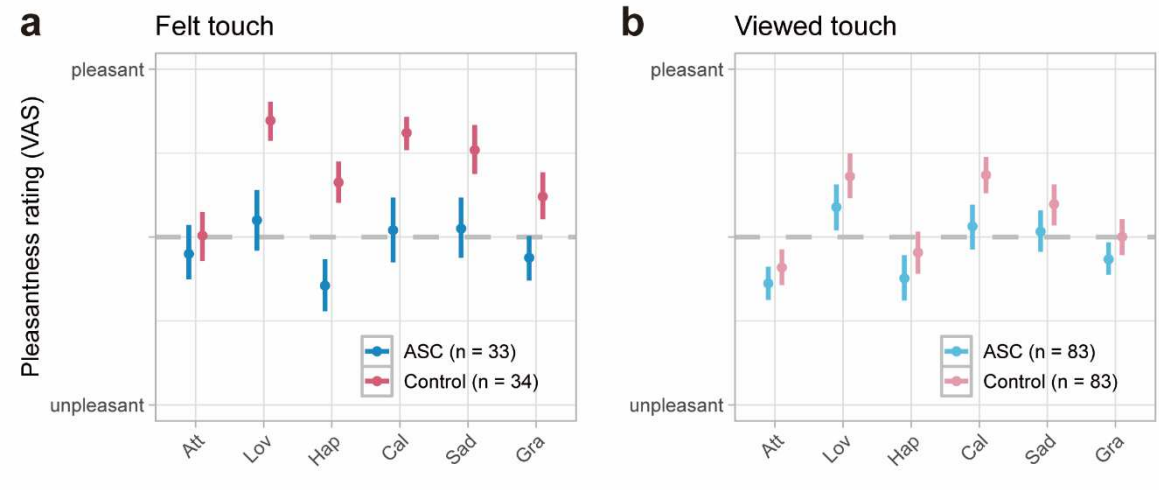


Figure 4 Perceived pleasantness of felt- and viewed-touch expressions.
Mean pleasantness ratings are shown for each touch expression with 95% bootstrapped confidence intervals. Pleasantness ratings were converted to values ranging from −10 to +10 for analysis. **a**, In the felt-touch experiment, pleasantness was higher in the control group than the ASC group for love (control, 95% CI [5.69, 8.06]; ASC, [-0.76, 2.75]), happiness (control, [1.93, 4.51]; ASC, [-4.54, -1.40]), calming (control, [5.24, 7.17]; ASC, [-1.54, 2.45]), sadness (control, [3.54, 6.52]; ASC, [-1.26, 2.27]), and gratitude (control, [0.99, 3.82]; ASC, [-2.47, 0.08]), as indicated by non-overlapping confidence intervals. **b**, In the viewed-touch experiment, the control group rated love, calming and sadness on the pleasant side of the scale, whereas the ASC group did so only for love, as indicated by confidence intervals that did not include zero. Pleasantness ratings for calming were higher in the control group than in the ASC group. Blue and pink denote ASC and control participants, respectively. Touch expressions are abbreviated: Att (Attention), Lov (Love), Hap (Happiness), Cal (Calming), Sad (Sadness), Gra (Gratitude).

Felt-viewed differences in autistic-trait associations remain after balancing participant characteristics

Because the felt- and viewed-touch experiments involved different participant samples, overlap weighting was used to balance age, gender, and diagnostic group between experiments. We then tested whether the AQ-related differences between felt and viewed touch were retained even after

balancing these differences in sample composition. The primary weighting model achieved covariate balance, with all standardized mean differences below 0.1.

For touch message agreement, higher AQ scores were associated with lower agreement in the felt-touch experiment (b = -0.0050, 95% CI [−0.0086, −0.0013]), whereas no clear association was evident in the viewed-touch experiment (b = 0.0008, 95% CI [−0.0029, 0.0044]). The association was significantly more negative for felt than viewed touch (interaction: b = 0.0057, 95% CI [0.0007, 0.0108], p = 0.025). For perceived pleasantness, higher AQ scores were associated with lower ratings in both experiments, with a larger negative association for felt touch (b = -0.23, 95% CI [−0.28, −0.17]) than for viewed touch (b = −0.12, 95% CI [−0.17, −0.07]; interaction: b = 0.10, 95% CI [0.03, 0.18], p = 0.006). A trait-balanced sensitivity model that additionally balanced AQ, STQ, and TAS distributions produced the same pattern of results (**Supplementary Table S1**). Thus, after balancing participant characteristics between experiments, the negative association between AQ and touch message agreement was specific to felt touch, whereas its negative association with perceived pleasantness was evident in both experiments and was stronger for felt than viewed touch.

Discussion

Individuals with more autistic traits displayed more difficulty recognizing the intent when being touched but not when viewing touch interactions. This indicates that the unique experiences of autistic individuals regarding social touch are more specifically linked to actual tactile sensations, not the conceptual understanding of the nonverbal communicative act. Higher autistic traits were also associated with experiencing the touch as less pleasant, and this effect was more pronounced for felt touch compared to only viewing the touch. Together, we suggest somatosensory-specific information processing in ASC as a basis for alterations in social touch processing.

The pleasantness findings suggest that autistic traits are associated with a reduced affective gain from direct social touch, rather than a simple aversion to being touched. The negative association between AQ scores and pleasantness is consistent with previous work using slow, gentle brushing optimized for C-tactile (CT) afferents[17]. The stronger association for felt than viewed touch may reflect the affective significance of being directly touched by another person. Consistent with this view, less positive attitudes towards social touch, which are characteristic of autistic individuals[19,26,31], were associated with lower pleasantness ratings. Our findings also align with evidence that autistic adults rated directly delivered human touch as more unpleasant than neurotypical adults[33]. Importantly, although ASC participants rated the touch as less pleasant than controls, their ratings remained, on average, around neutral rather than unpleasant. This pattern suggests an attenuated positive affective response to direct social touch, rather than a general aversion to touch. It may reflect reduced affective value from somatosensory input beyond the conceptual knowledge, prior bodily experience, or expectations that may contribute to viewed pleasantness. This attenuated positive affective response was evident across the more affective touch expressions, whereas attention, the less affective expression in our stimuli set, showed no clear group difference. Our subjective pleasantness findings seem consistent with the observation that autonomic responses differentiate affective from control touch in typical development but not ASC[33].

The absence of an association between autistic traits and the interpretation of viewed touch suggests that social meaning can be extracted from observed touch using conceptual knowledge that is relatively independent of direct somatosensory experience. Neurotypical (NT) participants activate the somatosensory cortex in response to viewing touch interaction, while ASC participants do not[31,34] – it is therefore possible that ASC individuals use a different strategy to interpret the viewed touch interactions, which is equally successful. While NTs might understand the intent of a viewed touch

through an embodied resonance response[35] – activating similar neural patterns as when receiving touch themselves – the ASC group might use higher order cognitive processing to classify the viewed touch expressions. Autistic individuals report to often mask in a neurotypical context[36], i.e. adapting specific, cognitively taxing strategies to "pass" as neurotypical. Masking strategies can be based on consciously learning and applying social rules[37]. It might be easier to report on the meaning of a viewed touch interaction using such learned social rules and norms, than applying them to tactile sensations on one's own body. It can further be expected that it is easier to learn social rules of viewed interactions (by observing others, watching movies, etc.) than of interactions that involve one's own body. The open-ended responses further support this interpretation. Even without predefined response options, both groups generated similar interpretations of viewed touch expressions, particularly for attention, love, happiness, and calming, suggesting that these expressions possessed clear visual movement signatures that reliably signaled their intended meanings. By contrast, sadness and gratitude were less consistently identified in both groups, indicating that these expressions were visually less transparent rather than specifically difficult for ASC individuals. The broadly convergent patterns obtained from human-coded and LLM-coded classifications also suggest that the absence of ASC-related differences in viewed touch agreement was not simply a result of the forced-choice format.

ASC-related differences in the central processing of social touch may lie not in conceptual knowledge, but in the processing of touch messages through direct tactile input. Because touch message agreement was associated with autistic traits when the expressions were felt, but not when they were viewed, the relevant difference appears to be tied to direct tactile input rather than to higher-order interpretation of the communicative act. The differences in sensory information processing in ASC individuals are specifically related to tactile stimuli rather than to higher order interpretation of the communicative act. While ASC individuals may cognitively understand the intent of the touch, they might not know how to interpret tactile stimuli, for instance due to a lack of experiential exposure to touch[17] or due to sensory overload as has been seen for other sensory qualities[38]. In the present study, ASC individuals also showed less positive attitudes towards touch, which may imply fewer opportunities for being touched[17], and these factors may provide fewer chances to calibrate how bodily touch sensations map onto intended social meanings, making felt touch harder to use and understand as a communicative signal.

ASC-related differences in touch message processing may also reflect altered lower-level peripheral or early spinal processing. Animal models point to altered tactile processing as early as the dorsal horn of the spinal cord[39,40]. Human developmental work has suggested an association between tactile defensiveness at sites innervated by unmyelinated low-threshold (C-tactile, CT) afferents and social impairment in children with ASC[41]. However, the group differences observed here were not limited to touch types that have been shown to strongly activate CT afferents (e.g. love), but also extended to fast tapping expressions that poorly activate CTs but engage other touch receptors (attention, happiness)[32]. Touch message agreement requires mapping the spatiotemporal pattern of tactile input onto social meaning[42]. Thus, while CT-related mechanisms may contribute to altered touch pleasantness in ASC, reduced touch message agreement is not easily explained by a strictly CT-specific alteration.

The standardized expressions were originally developed based on undirected types of touch exchanged between individuals recruited from the general population when prompted with certain situations or key words[9]. In the present study, the expressions were performed by an experimenter who was a stranger to the participant. The control-group $F1_{micro}$ value fell within the 95% confidence intervals previously reported for the same standardized expressions delivered by strangers[9].

However, these results cannot say anything about touch interactions between autistic individuals with their close ones and in a private, intimate, and controllable situation. The context of touch communication here is more similar to touch between strangers in a public setting, which would probably rely on shared cultural beliefs and norms, i.e. that love is typically communicated by slow stroking. This does not necessarily mean that all individuals communicate love through this specific gesture in their individual relationships. However, our previous research demonstrates that this love-gesture (and the other gestures) seems to be generally understood within the same community that we recruited in this study[9]. ASC individuals nevertheless performed above chance level in the felt-touch condition, indicating that direct tactile contact still conveyed meaningful information.

Future work could repeat the initial step of developing the gestures with autistic individuals to see whether they would intuitively use other types of touch to communicate emotions – and whether such different types of tactile communication styles would be understood better by other autistic individuals and less well by NTs. This would be expected based on the double empathy problem theory, which suggests that social "difficulties" in autistic individuals are actually mismatches with neurotypical behaviors, while social interactions within autistic dyads are better matched and do not evoke such misattunements[37,43,44].

Social interactions in daily life often involve tactile encounters, including touching and being touched by other people. Notably, although we use all our senses to perceive social cues, being touched by another person is a most intimate exchange; a gentle caress can convey a rich message, perhaps far exceeding that in a facial expression or quality of voice. This study found that autistic individuals struggled with recognizing intended messages and experienced lower pleasantness during felt touch expressions, highlighting their unique challenges in touch communication. These findings are important for understanding disruptions associated with conditions characterized by social alterations or differential sensory processing, such as autism.

Methods

General information

All experimental protocols were approved by the Swedish Ethical Review Authority (no. 2020/039-26) and were conducted in accordance with the declaration of Helsinki (2008). Two independent experiments were conducted under distinct conditions: a felt-touch condition (Experiment 1) and a viewed-touch condition (Experiment 2). Participants were recruited such that demographic characteristics were matched as closely as possible across experiments, particularly with respect to age and gender. The distributions of age and gender proportions for each group (ASC and Control) in each experiment are shown in **Supplementary Fig. 1**.

Sample sizes reflected the feasibility of recruiting ASC participants across the two experiments. The target sample size for the viewed-touch experiment was guided by power calculations based on AQ–outcome associations observed in the felt-touch experiment. Sensitivity power analyses using the final sample sizes indicated that the experiments had 80% power at $\alpha = 0.05$ to detect AQ–outcome correlations of $|r| = 0.216–0.332$, depending on experiment and outcome[45] (**Supplementary Table S2**).

Participants

We recruited participants through the special education program for children with ASC in Linköping (IVAS school), via advertisements posted on social media and other online platforms, as well as through the adult psychiatry department of Linköping hospital. Control participants were recruited through advertisements and other local schools. Participants provided informed consent and in case

they were younger than 18, their parents provided consent as well. Participants were informed that they could withdraw from the study at any time without giving a reason.

In the felt-touch experiment, ASC status was confirmed through enrolment in the special education program, where enrolment required an ASC diagnosis, or by self-report for participants recruited through advertisements. In the viewed-touch experiment, participants were assigned to the ASC or control group based on their response to the question “Have you ever been diagnosed with Autism Spectrum Disorder/Asperger’s Syndrome?” (Yes/No).

Inclusion criteria

Participants were required to be 15 to 40 years of age and to have sufficient knowledge of Swedish or English.

Exclusion criteria

Participants were screened regarding their history of psychiatric disorders and substance dependence through an interview conducted before booking in the felt-touch experiment or an online screening form in the viewed-touch experiment. The screening included the following three questions: "Have you ever been diagnosed with bipolar disorder or psychosis?", "Do you regularly take recreational drugs (e.g., cannabis, cocaine, MDMA …)?", and "Do you regularly drink 5 or more alcoholic drinks per day?" Participants who self-reported psychosis, bipolar disorder, or substance dependence were excluded.

Procedure

Participants completed questionnaires and two social touch tasks: a touch communication task, in which they judged the social meaning conveyed by each touch expression, and a touch pleasantness rating task, in which they rated how pleasant the expression felt. In the felt-touch experiment, the touch expressions were delivered to the participant’s forearm by a trained experimenter. In the viewed-touch experiment, participants completed corresponding tasks after viewing videos of the same standardized touch expressions. Each experimental session took no more than one hour.

In the felt-touch experiment, participants rested their left arm on the armrest of a chair and used their right hand to respond with a computer mouse. A curtain was placed between the participant and the experimenter, with the participant’s left arm positioned on the experimenter’s side of the curtain (**Fig. 5**). The participants were told that the experimenter would touch their forearm in a few different ways. Participants were aware that the experimenter could not see their responses. The experimenter received auditory cues through headphones indicating which touch expression to deliver. Participants were told to answer according to what they felt, and that there was no “right” answer. The order of the questionnaires, touch communication task and touch pleasantness rating task varied across participants, although the two touch tasks were always administered consecutively.

In the viewed-touch experiment, participants first selected Swedish or English, read the participant information, including that none of their information could be traced back to them as individuals, and provided electronic informed consent. They filled out screening questions to determine eligibility. If they met the eligibility criteria, they filled in demographic information and whether they had received an autism diagnosis. Eligible participants then proceeded to the online tasks. Participants first completed the touch pleasantness rating task, followed by the touch communication task. Finally, participants completed the questionnaires.

Touch Communication Task

The touch communication task used six touch expressions that we previously developed to communicate happiness, sadness, love, gratitude, attention, and calming[9].

In the felt-touch experiment, the experimenter delivered each touch expression to the participant's forearm. Each expression was presented 10 times in a pseudo-randomized order. On each trial, the experimenter was presented with one of the cues (attention, love, happiness, sadness, calming, gratitude). After each touch had been performed for 10 s, participants were presented with buttons on a screen labelled with the six intended messages and included an additional option "They are trying to communicate something else." Participants had to select one to indicate what they thought the experimenter was communicating. The locations of the buttons on the screen were shuffled on every trial, and no feedback was provided. The touch communication task was guided by a custom Python script using PsychoPy[46].

In the viewed-touch experiment, participants watched videos of the standardized touch expressions and judged what message the toucher was trying to communicate. Participants were randomly assigned to either a forced-choice version, which used the same seven options as the felt-touch experiment, or an open-ended version, in which they typed their interpretation in a free-text response box. The order of video presentation was randomized, and the order of response options was randomized in the forced-choice version.

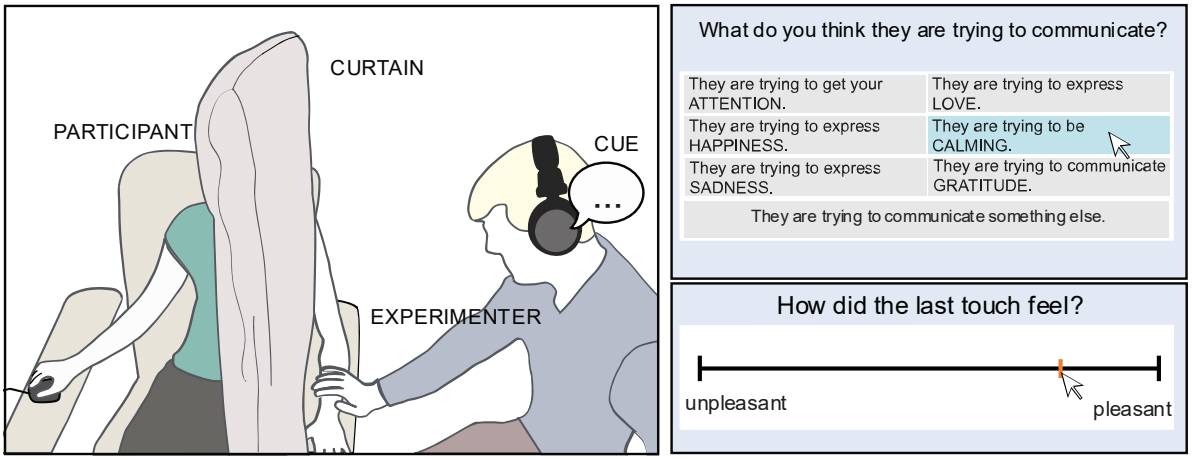


Figure 5 Experimental setup for Experiment 1 (felt touch).
Participant rested their left forearm on the experimenter's side of a curtain and used their right hand to respond. The curtain prevented visual contact between the participant and experimenter, and the experimenter could not see the participant's responses. The top-right panel shows the response screen for the touch communication task, and the bottom-right panel shows the visual analog scale used for pleasantness ratings.

Touch Pleasantness Rating Task

Participants judged the perceived pleasantness of the standardized touch expressions. In the felt-touch experiment, each touch expression was delivered to the participant's forearm, and participants rated how the touch felt using a visual analog scale (VAS) with endpoints labelled "unpleasant" and "pleasant" (in Swedish "obehaglig" and "behaglig") (**Fig. 5**). In the viewed-touch experiment, participants watched videos of the touch expressions and rated how pleasant it would feel if someone touched them in that way using the same type of visual analog scale. The order of touch expressions was randomized.

Data processing and analysis

All data processing and statistical analyses were conducted in R (version 4.3.2).

Participant characteristics

Participant characteristics were summarized by experiment and group. Age distributions and gender proportions were visualized for the ASC and control groups in each experiment (**Supplementary Fig.**

1a). Age differences across experiments were first examined separately within the ASC and control groups using one-way ANOVA. Age differences between the ASC and control groups were then assessed separately for each experiment using Welch's two-sample t-tests. Effect sizes for group differences in age were quantified using Cohen's d.

Questionnaire scores were compared between the ASC and control groups separately within each experiment using independent-samples t-tests. Effect sizes were quantified using Cohen's d. Because these comparisons were used to characterize the samples, questionnaire results are reported descriptively with effect sizes (**Supplementary Fig. 1b**).

Message agreement

Responses in the touch communication task were used to quantify message agreement, defined as the extent to which each participant's interpretation corresponded to the intended message of the standardized touch expression. Confusion matrices were constructed with intended messages as rows and participants' interpretations as columns.

Message agreement was quantified using F1 scores. For each expression, F1 was calculated as the harmonic mean of precision and recall: F1 = 2 x (Precision x Recall) / (Precision + Recall)[47]. Recall was defined as the proportion of trials for a given intended expression that were interpreted as that expression. Precision was defined as the proportion of responses assigned to a given interpretation that corresponded to the matching intended expression. Thus, F1 accounts for both false negatives and false positives. For example, the F1 score for "attention" incorporates both cases in which the attention expression was interpreted as another message and cases in which another expression was interpreted as attention.

$F1_{micro}$ was used as an aggregate measure of overall message agreement across expressions[48]. For each participant, true positives, false positives, and false negatives were pooled across expressions to compute micro-averaged precision and recall, and $F1_{micro}$ was then calculated as their harmonic mean.

Nonparametric bootstrapping with 1,000 replicate samples was used to estimate confidence intervals for F1 and $F1_{micro}$ scores. For expression-level comparisons, non-overlapping 95% confidence intervals were used to indicate group differences.

Pleasantness rating

For the pleasantness rating task, ratings were summarized for each touch expression and across expressions. VAS responses anchored by "unpleasant" and "pleasant" were converted to numerical values ranging from −10 to +10 for analysis. Confidence intervals for pleasantness ratings were estimated using bootstrap resampling. Group differences were evaluated using non-overlapping 95% confidence intervals.

Correlation analyses

Pearson correlation analyses were used to evaluate associations among touch message agreement, perceived pleasantness, and individual traits measures. For each participant, touch message agreement was summarized using $F1_{micro}$ across expressions, and perceived pleasantness was summarized as the mean pleasantness rating across expressions. Correlations were tested using a family-wise alpha of 0.05 with Holm-Bonferroni correction for multiple comparisons.

Open-ended response classification

Open-ended responses from the viewed touch task were analyzed to examine participants' interpretations without the constraints of forced-choice response options. Responses written in

Swedish were translated into English by a Swedish–English bilingual person who was not involved in response classification.

We used three complementary classification procedures. First, to compare open-ended responses with the original touch messages, three human evaluators independently classified each response using the six intended-message labels. Responses were presented in randomized order. All classifications were pooled, so that each response contributed three entries to the human-coded confusion matrix. Second, OpenAI GPT-4o was used as a standardized model-based classifier, with the same instruction and labels as the human evaluators. This classification was repeated in six independent runs, and all outputs were pooled, so that each response contributed six entries to the model-coded confusion matrix. Third, to examine participants' descriptions of the viewed touch expressions beyond the original intended-message labels, GPT-4o classified the responses without providing the intended touch-message labels. The full set of translated open-ended responses was first presented to the model to generate the label set. The model was instructed to generate exactly six broad one-word labels representing emotional or communicative intentions that together covered as many responses as possible, with "other" included as an additional label. The prompt also specified that responses indicating uncertainty or lack of knowledge should be assigned to other rather than treated as a separate category. The response-derived categories were then used in a second GPT-4o classification step. Using the same per-response classification procedure as above, the model assigned each response to the best-fitting response-derived categories.

Detailed prompts and analysis scripts are provided in the online repository see below).

Cross-experiment analyses

To account for measured differences in participant composition between the felt- and viewed-touch experiments, we used propensity score overlap weighting. Propensity scores were estimated using a generalized linear model in which experiment was regressed on age, gender and diagnostic group. Overlap weights were then derived to target the population with the greatest covariate overlap between experiments.

Covariate balance was assessed using standardized mean differences, with values below 0.1 considered to indicate adequate balance. Weighted regression models were fitted separately for touch message agreement and perceived pleasantness using the overlap weights. Each model included AQ, experiment, the AQ-by-experiment interaction, age and gender.

In sensitivity analyses, AQ, STQ and TAS were added to the propensity score model to further balance trait distributions between the felt- and viewed-touch samples. The weighted outcome models were otherwise unchanged.

Questionnaires

The participants completed four questionnaires: Autism-Spectrum Quotient (AQ)[49], Broad Autism Phenotype Questionnaire (BAPQ)[50], Social Touch Questionnaire (STQ)[51], Toronto Alexithymia Scale (TAS)[52]. Demographic information, including age, gender, country of residence, was also collected.

Data and materials availability

De-identified data, analysis code and the video stimuli are available in an online repository at https://github.com/LHTMR/touch-comm-autism/tree/submission-v1, with a DOI assigned through Zenodo upon publication. Raw identifiable data will not be publicly shared.

Acknowledgements

We wish to thank Dorota Persson and Maja Lindberg for delivering touches, and Ilona Szczot for consulting on data analysis.

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