The language of social touch is intuitive and quantifiable

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Abstract: Touch is a powerful communication tool, but we have a limited understanding of the role played by particular physical features of interpersonal touch communication. In this study, adults living in Sweden performed a task in which messages (attention, love, happiness, calming, sadness and gratitude) were conveyed by a sender touching the forearm of a receiver, who interpreted the messages. Two experiments (n=32, n=20) showed that within close relationships, receivers could identify the intuitive touch expressions of the senders, and we characterized the physical features of the touches associated with successful communication. Facial expressions measured with EMG varied by message, but were uncorrelated with communication performance. We developed standardized touch expressions and quantified the physical features with 3D hand-tracking. In two further experiments (n=20, n=16), these were conveyed by trained senders and were readily understood by naïve strangers. Thus, the possibility emerges of a standardized, intuitively understood language of social touch.

21 Statement of Relevance: Communicating via touch is a pre-cursor of spoken language – both in
22 an evolutionary sense, and in human infant development. This suggests the possibility of an
23 intuitive touch language with widely understood features, similar to how emoji convey facial
24 expressions. We identify a number of primitive elements of touch expressions used during
25 interpersonal communication, and describe them in terms of their physical characteristics. We
26 demonstrate that this approach can be used to compose non-verbal social messages like love,
27 attention, happiness, sadness, gratitude and calming, and that these messages are intuitively
28 understood by strangers with minimal context, and without feedback or training.

29 Introduction

30 Interpersonal touch is important for social interaction, precedes language as a form of
31 communication in infants (Hertenstein, 2002), and is linked to the evolutionary development of
32 language (Dunbar, 1993). In non-human primates, touch in the form of grooming is used for
33 reconciliation after conflicts and promotes group cohesion (Dunbar, 2010). The way that adult
34 humans use interpersonal touch may be governed by this evolutionary and developmental
35 heritage. That is, there may exist neural infrastructure that is related to how the particular
36 features of interpersonal touch (e.g. tapping, stroking or holding) are used for different purposes
37 (e.g. getting someone's attention, soothing or expressing affection). However, it is currently
38 unknown if humans communicate via a common repertoire of touch gestures, or what determines
39 successful communication.

40 There are challenges to investigating inter-personal touch in humans: touch usually happens in
41 private and complex social contexts (Cekaite & Kvist Holm, 2017), and is governed by the
42 relationship between the people involved (Suvilehto et al., 2015, 2019). Nonetheless, several
43 studies show that touch alone effectively communicates emotions such as anger, fear, disgust,
44 love, gratitude, sympathy, happiness, and sadness (Hertenstein et al., 2009; Hertenstein, Keltner,
45 et al., 2006; Hertenstein, Verkamp, et al., 2006). Indeed, touch is the preferred channel over body
46 language and facial expressions for expressing both love and sympathy (App et al., 2011).
47 Happiness, sadness, anger and disgust are also successfully communicated, despite touch not
48 being the preferred communication channel, likely because redundancy improves communication
49 success (App et al., 2011).

An outstanding question is to what extent interpersonal touch strategies are universal, culturally determined, or idiosyncratic. One study shows that couples are more effective at touch communication than strangers (Thompson & Hampton, 2011), suggesting that couples may develop an idiosyncratic set of touch expressions, or touch language. Other studies describe the physical features of social touch (Hertenstein et al., 2009; Hertenstein, Keltner, et al., 2006; Jung et al., 2015; Masson & Op de Beeck, 2018), but do not evaluate the different strategies for communication effectiveness. A recent study shows that the speed of stroking and the touched body location influence the touch receiver's judgments about the emotional state and intentions of the person touching them, even when they are not trying to communicate a specific message (Kirsch et al., 2018). These findings suggest that some physical features of interpersonal touch could be reliably mapped to different messages.

Observing facial expressions can be a source of additional information for the receiver of a touch communication (Tsalamlal et al., 2018, 2015), and facial muscle activity changes in a way that is consistent with positive affect when people are gently stroked by a soft brush (Mayo et al., 2018; Pawling et al., 2017; Ree et al., 2020). It is not known whether there is a link between the affective state as measured by facial muscle activity and the capacity to either convey or interpret messages via touch.

In the current study, we investigated whether it is possible to optimize touch strategies by selecting specific physical features, so that touch messages can be understood broadly within one cultural context, outside of a close relationship. We first identified, within close relationships, the physical features of interpersonal touch (e.g. slow stroking, tapping with a finger) that were most associated with success and failure to communicate cued touch messages. We also investigated facial expressions that accompany touch communication, using facial electromyography

(fEMG), and tested whether variations in facial expressions were related to performance on the touch communication task.

We then developed standardized touch expressions based on the most successful touch features that we identified for each message. These were delivered by trained experimenters to naïve strangers, and performance on the communication task was compared to that between people in a pre-existing relationship. We also present a quantitative description in terms of motion and contact area characteristics for the standardized touch expressions.

Methods

We recruited pairs of participants with an existing close relationship (Table 1) to participate in our touch communication task (Figure 1A). The participants assigned to the role of sender were required to communicate a series of messages using touch alone, using any gestures they felt were appropriate. The receiver then had to identify the message from a list of options. Because we gave no instructions about the touch strategies to use, we refer to this as ‘intuitive’ touch communication to contrast it with the standardized touch strategies that we later developed.

Participants

For the intuitive touch experiments (experiments 1 and 2), we recruited pairs of adult participants with a pre-existing relationship in which they felt emotionally close and were comfortable touching each other in a normal social context. For the standardized touch experiments (experiments 3 and 4), participants were recruited individually. Table 1 offers a detailed description of our sample and an overview of the experiments. Participants were recruited from online and poster advertisement targeting the general community and the university community

94 at Linköping University, Sweden. This is an international community, but we did not collect any
95 data on the cultural background of our participants. All participants provided informed consent,
96 and the study was conducted in accordance with the regulations of the Regional Ethics
97 Committee who approved the study. In addition to the touch communication task, participants
98 completed a number of questionnaires, detailed in the Supplemental Material.

Table 1. Overview of experiments and participants (* indicates data presented in a separate manuscript; ** indicates small deviations from the intended number of trials, see text for details).

	Experiment 1	Experiment 2	Experiment 3	Experiment 4
Touch type	Intuitive (both roles)	Intuitive (one role)	Standardized (expert 1)	Standardized (experts 2 & 3)
Measurements	Communication task Facial EMG Video recording	Communication task Functional MRI*	Communication task	Communication task Hand-tracking
N participants	32 (16 pairs)	20 (plus partners)	20	16
N trials	960 (6 cues x 5 repeats x 32 participants)	2400 (6 cues x 20 repeats x 20 receivers)	1750** (6 cues x 15 repeats x 20 participants)	1916** (6 cues x 20 repeats x 16 participants)
Age range (median)	19 – 46 (24)	19 – 32 (22) (partners 19 – 40 (22))	20 – 40 (25)	20 – 35 (24)
Sex	15 female 17 male	9 female 11 male (partners 11F, 9M)	9 female 11 male	5 female 11 male
Relationships	10 romantic (9 FM, 1MM) 5 friendships (2FF, 2MM, 1FM) 1 family (FM)	9 romantic (1FF, 8FM) 11 friendships (5FF, 6MM)	20 strangers (1 experimenter 20 participants)	16 strangers (2 experimenters 16 participants)

In experiments 1, 3 and 4, the target number of participants was 15 – 20, based on previous research (McIntyre et al., 2019) in which 95% confidence intervals of approximately $\pm 10\%$ performance was achieved at the cue level. For experiment 2, the target was set at 20

participants, the recommended minimal sample size for functional imaging studies (Murphy & Garavan, 2004). The number of trials per participant was based on trying to maximize the number of trials while staying within an acceptable duration for the participants. This was smaller for experiment 1 due to the time taken to apply facial EMG electrodes. For experiment 2, we initially recruited 22 pairs, but one pair had to be excluded from the final analysis because they did not follow the task instructions. Another pair ended the experiment early because the person in the scanner felt claustrophobic. In experiments 3 and 4 some trials were not performed due to experimenter or technical error. In experiment 3, there were 3 participants for which only 70, 72 and 78 of the intended 90 trials were obtained; and in experiment 4, there two participants for which only 118 of the intended 120 trials were obtained.

Intuitive touch communication task

We chose six messages to cue: attention, love, calming, happiness, sadness and gratitude (see Table 2 for full-sentence cues). We included a mix of touch messages and required only that participants were sufficiently acquainted to be comfortable touching each other. Our goal was to try to capture a variety of different interpersonal touch interactions that may occur in natural settings. Some of the cues communicate the emotional state of the sender (happiness, sadness), some attempt to elicit a response from the receiver (attention, calming), and some refer to an existing social context (love, gratitude, calming). These are messages that people generally want to communicate using touch and were adapted from those used in a previous study (McIntyre et al., 2019) to reduce conceptual overlap between messages.

Participants were assigned roles: one as the sender, the other as the receiver. The sender's task was to send messages by touching the receiver's arm. The receiver's task was to guess what the

127 message was. The receiver sat in a chair (experiment 1) or lay in the MRI scanner (experiment 2;
128 MRI data are presented in a separate manuscript) with one arm resting passively, accessible to
129 the sender. The sender and receiver could not see each other's faces, which were obscured by a
130 curtain (experiment 1) or the MRI scanner (experiment 2). Participants were instructed to remain
131 quiet throughout the touch communication task, not talking or making any other noise such as
132 laughing or sighing. The touch communication task was guided by a custom python script using
133 Psychopy (Peirce, 2007). On each trial, the sender was presented with one of the sender cues
134 shown in Table 2. The sender was told to touch only the forearm, and that they could perform
135 any kind of touch that they felt was appropriate. After each touch was performed, the receiver
136 was presented with buttons on a screen labelled with all of the receiver response options shown
137 in Table 2, and had to select one to indicate what they thought the sender was communicating.
138 The cues were presented in a pseudo-random order, and the locations of the buttons on the screen
139 were shuffled on every trial. No feedback was provided.

140 *Table 2. Cues for the intuitive touch communication task. The 'other' option was only presented to the*
141 *receiver, and only in experiment 1. In experiment 2, the receiver had 7 seconds to respond, otherwise the*

142 response was labelled 'timeout'. Participants were instructed that 'your partner' referred to their partner
 143 in the task.

Cue words	Sender cues	Receiver choices
attention	You just heard about something that your partner might find interesting. Try to get their ATTENTION through touch.	Your partner is trying to get your ATTENTION.
love	Think of all the wonderful qualities that your partner has, and how they enrich your life. Try to express LOVE through touch.	Your partner is trying to express LOVE.
happiness	You have just received good news. You are feeling very happy and you want to let your partner know. Try to express HAPPINESS through touch.	Your partner is trying to express HAPPINESS.
sadness	You have just received bad news. You are feeling very sad and you want to let your partner know. Try to express SADNESS through touch.	Your partner is trying to express SADNESS.
calming	Your partner is feeling upset thinking about a situation that cannot be changed. Try to be CALMING through touch.	Your partner is trying to be CALMING.
gratitude	Your partner has just helped you solve a problem. Try to communicate GRATITUDE through touch.	Your partner is trying to communicate GRATITUDE.
other/ timeout		Your partner is trying to communicate something else.

144

145 There were some minor differences in how the task was conducted in experiments 1 and 2. In
 146 experiment 1, the sender could take as long as they wanted to perform the touch, and controlled
 147 the pace of the experiment. After performing the touch communication task, the participants
 148 switched roles so that the sender became the receiver and vice versa, and the touch
 149 communication task was performed with the new roles. The experimental session consisted of
 150 two blocks, one for initial and one for swapped roles, of 30 trials each. Additionally, each cue

was also presented once at the beginning of the first block (initial roles), in which the receivers could type in open-ended responses instead of being offered the forced-choice buttons. In addition to the touch communication task, facial EMG responses of the participants were measured, and the touches were recorded on video (details below).

In experiment 2, the task was conducted while the receiver was lying in an MRI scanner, and so the task was modified slightly. In addition to the instructions described above, the senders were told not to perform any shaking movements in order to avoid movement artifacts. Additionally, they were required to perform each touch for exactly 10 seconds to facilitate analysis of the fMRI data. To control the timing of the experiment, the sender heard the single word cues (e.g. ‘attention’) via headphones, followed by a countdown to ‘go’ and ‘stop’ signals to start and stop touching. So that the senders had time to consider how to perform the touch, as they did in experiment 1, the senders were familiarized with the full cues (Table 1) before entering the scanner. The receiver was not given the ‘other’ option, but if they failed to answer within 7 seconds, a ‘timeout’ response was recorded and the next trial was presented. The participants did not swap roles. The experimental session consisted of two blocks of 60 trials each.

Standardized touch communication task

In the expert touch experiments, the participant was always the receiver and a trained experimenter was the sender. Based on the video observations of the common physical features of touch communication behavior between people in a close relationship (experiment 1), we developed a set of 10-second standardized touch gestures to each of the six emotional messages (Supplemental Material, Movies S1-S6). These standardized gestures were applied by trained experimenters to the forearm, who received spoken cues via headphones.

In experiment 3, one trained experimenter performed all the gestures (expert 1), and the experimental session consisted of one block of 90 trials. In experiment 4, two different trained experimenters performed the gestures (experts 2 and 3), and the experimental session consisted of two blocks of 60 trials each, usually with a different expert performing the touches in the two blocks. Because people tend to find touch from women more acceptable (Suvilehto et al., 2019), the trained experimenters were all female.

Data analysis for touch communication

To evaluate performance on the touch communication task, we used F1 as the outcome measure. F1 is a measure of performance which is suited to classification tasks in which there are more than two categories, and is appropriate when both misses and false alarms are equally undesirable. F1 is the harmonic mean of Recall and Precision, $F1 = 2 \times (\text{Precision} \times \text{Recall}) / (\text{Precision} + \text{Recall})$. Recall is the rate of cues correctly identified when present (also called hit rate), and Precision is the rate of cues correctly identified when the receiver chose that cue. A separate set of analyses were also conducted using Recall as the dependent variable, which yielded similar results and patterns of significance (not reported).

We conducted separate analyses for each experiment, using a generalized linear mixed effects model with a logit link function for F1 performance score as the dependent variable. For experiment 1, we used fixed effects for cued word and roles (initial or swapped), and a random intercept term for participant. For experiments 2-4, we used a fixed effect for cued word and a random intercept term for participant. When comparing intuitive and standardized touch, we used fixed effects for touch type (intuitive or expert) and cued word, and a random intercept term for participant. To test for significance, parametric bootstrap with 1000 samples was used to produce likelihood ratios for full versus reduced models. Because we did not have the same

number of judgments for receivers in different experiments, the weight term supplied to the model reflected the number of trials for each receiver-cue combination. Holm correction was used for all post-hoc tests comparing overall performance and performance of individual cues against chance, and for all post-hoc pairwise comparisons, to obtain family-wise $\alpha = 0.05$ separately for each model. Analyses were performed using R (R Core Team, 2018) and the package afex (Singmann & Kellen, 2019), and figures were created using the packages ggplot2 (Wickham, 2016) and patchwork (Pedersen, 2017).

Facial electromyography (fEMG)

In experiment 1, emotional expression in the face during the touch communication task was assessed by measuring corrugator and zygomatic reactivity in response to the touch associated with each cue from both participants using a dual wireless EMG system (Dual Wireless EMG BioNomadix Pair, Biopac, Goleta, CA, USA). The corrugator supercilii muscle, which furrows the eyebrows, is active during frowning, and stimuli with negative valence increase its activity, while stimuli with positive valence decrease its activity (Larsen et al., 2003). The zygomaticus major muscle, which lift the cheeks and lips, is active during smiling, and is associated primarily with positive affect (Larsen et al., 2003) and particularly with high arousal positive affect (Fujimura et al., 2010). Facial EMG of the corrugator and zygomatic muscles was measured in microvolts (μV). EMG was measured over left brow and cheek and ground sensor on the forehead (Fridlund & Cacioppo, 1986) with 4 mm Ag/AgCl electrodes. Impedances were kept below 20 k Ω . EMG signals were amplified, 10–500 Hz band pass filtered, digitized at 1000 Hz, 50 Hz band stop filtered, rectified, and integrated over 20 ms by using EMG100C amplifiers, and MP160 Data Acquisition System and AcqKnowledge software from Biopac Systems (Goleta,

CA, USA). The script guiding the touch communication task simultaneously delivered triggers to the EMG data capture system via parallel port, and played an audio signal that was captured by the video recording. This synchronizing signal was sent each time the sender pressed a button on the keyboard to indicate that they were about to start performing the touch. Research assistants then manually inspected the video recordings of every trial to find the frame following this signal on which the touch actually started. We then used the time delay from the synchronization signal to align the touch onset with the fEMG recording. The video recordings were made at 25 frames per second, giving us a precision of 40 ms for identifying the onset of the touch (the audio was sampled at 44.1 kHz and the fEMG at 1 kHz, meaning the visual onset of the touch had the lowest temporal resolution). The exact timing of the onset and offset for the touches was determined in this way for all participants, except for two blocks that lacked video data. In this case the onset of touch was instead determined by the timing of the button-press made by the sender to indicate they were about to start touching.

Data processing and analysis for fEMG

For each trial, we extracted a 200 ms long baseline preceding touch-onset and a 4 s long stimulation segment from touch-onset. This time-window was chosen based on inspection of the data plotted over time (Figure S2), which shows that it is long enough for effects to stabilize, while still including sufficient data from shorter trials. For the ‘attention’ cue, which provoked the shortest touch durations, 35% of trials lasted longer than 4 s. The baseline period was between 1200 and 1000 ms before touch onset. This was because the sender’s fEMG responses had already started to change immediately before onset because they read the cue before starting to perform the touch (Figure S2). Automatic artefact rejection was applied to the data within the selected baseline and stimulus periods using a custom R script, and based on a procedure

previously validated in a large sample by comparison with manual inspection (Künecke et al., 2014). Data were flagged if the range within a sliding 50-ms window exceeded three times the standard deviation of the participant's full dataset. Data within the selected time-window were down-sampled to 100ms bins, and a bin was rejected if it contained any flagged data samples. Trials were included in the analysis if after artifact rejection they had at least ten bins remaining (i.e. a total of 1 s), including at least one from the baseline period. Out of 971 trials recorded, the following number of trials remained in the analysis after artefact rejection: 939 trials for the zygomaticus activity of the sender (attention: 155 love: 162, happiness: 148, calming: 161, sadness: 158, gratitude: 155); 954 trials for the zygomaticus activity of the receiver (attention: 151, love: 158, happiness: 162, calming: 162, sadness: 161, gratitude: 160); 924 trials for the corrugator activity of the sender (attention: 152, love: 160, happiness: 150, calming: 156, sadness: 154, gratitude: 152) and 935 trials for the corrugator activity of the receiver (attention: 149, love: 160, happiness: 156, calming: 157, sadness: 158, gratitude: 155).

The data were z -scored within each participant for each muscle separately across all trials thus resulting in the standardized activity of zygomaticus and corrugator for every participant. For each trial, the mean z score during the baseline phase was subtracted from the mean z score during the touch phase to obtain the difference scores, reflecting the muscle activity in response to the touch relative to the baseline period preceding touch. We used a mixed linear model with difference scores as the dependent variable, a fixed effect for cued word and a random intercept term for participant. To test for significance, the Kenward-Roger approximation based on a modified F test was used (Singmann & Kellen, 2019).

For the machine learning analysis, we used a random forest classifier (Tin Kam Ho, 1995) with 1,000 estimators (decision trees) using the Scikit-learn package (Pedregosa et al., 2011) with

Python 2.7. The estimators are constructed in randomly selected subspaces defined by the input features (from the EMG recordings), and the classifier automatically finds the most important features for predicting the cue. As input to the classifier, six features were selected from the cleaned dataset for each muscle, resulting in 12 features total for either sender or receiver. These six features were chosen as described in (Jerritta et al., 2014; Picard et al., 2001) and consist of the: 1) mean of the raw signal, 2) standard deviation of the raw signal, 3) mean of the absolute values of the first differences of the raw signals, 4) mean of the absolute values of first differences of normalized signals, 5) mean of the absolute values of second differences of raw signals, and 6) mean of absolute values of second differences of normalized signals. Ten-fold cross validation was performed to determine classifier accuracy and uncertainty, and to prevent overfitting. Statistical analysis of classifier accuracy was performed (Scipy statistics package, Python 2.7). To determine whether classification accuracy was better than random, the number of correct classifications for each cued emotion was compared to a random classifier in a contingency table and a χ^2 test of independence of variables was then used to determine statistical significance.

Video recording

In experiment 1, the touch communication task was recorded on video so that we could capture the features of touch such as duration, speed, target area, intensity and type of touch. Care was taken to record a small area focused on the arm of the receiver, so as to avoid recording the participants' faces. On the rare occasions when a participant's face entered the frame, this was edited to obscure the face, and the original recording was destroyed. Videos were coded by three

research assistants who were unaware of the cue presented to the sender. The timing of each touch event was recorded, and they were coded for target location, intensity, and type. The coding scheme was adapted from that reported in (Hertenstein, Keltner, et al., 2006). Locations were categorized as the hand, wrist, lower forearm (distal) and upper forearm (proximal). Intensity was coded as ‘light’ (skin indentation or arm movement minimal. E.g. slow stroking, holding), ‘moderate’ (moderate skin indentation or arm movement. E.g. fast stroking, squeezing), or ‘strong’ (considerable skin indentation or arm movement. E.g. shaking). Touch type was selected from a long list of descriptors: 'holding', 'pressing', 'lifting', 'interlocking', 'hugging', 'tossing', 'pulling' and 'pushing', 'stroking', 'squeezing', 'swinging' and 'massaging', 'pinching', 'rubbing', 'tapping', 'shaking', 'patting', 'poking', 'hitting', 'picking', 'scratching', 'slapping', 'tickling' and 'trembling'.

Data processing and analysis for video recordings

Video data were annotated with ELAN (2018). For two sessions (one half of the experiment for each of two different pairs), recordings were not made due to equipment failure. Annotation text was automatically matched in R against the key-words included in the coding scheme for touch type, location, and intensity. Trials with missing data were checked for typos and other labelling errors, which were manually corrected. Of the recorded sessions, 53 trials (2.5%) were excluded due to missing data, obscured touches, and rare touch events that did not fit the coding scheme. The touched locations were simplified for presentation in Figure 1. The “wrist” was included in the “distal arm” category, and the “whole arm” category included touches that covered at least two different location categories.

To determine the most effective touch strategies, the type, location, and intensity of the touches were evaluated with respect to performance on the touch communication task, for every trial. The combination of type, location, and intensity gave the full description of each touch action. Some senders used multiple touch actions on a single trial, including in some cases swapping back and forth between different touch actions. For this reason, we did not want to simply count the number of times a touch action appeared, since these trials would mean that these repeated touch actions would be overrepresented. Furthermore, on some trials in which senders used multiple touch actions, one action appeared to be the dominant strategy, with more time spent on it than other actions. For this reason, we did not want to simply count whether a touch action appeared in a trial. We decided to capture how prominent a particular touch action was for a given trial by using the proportion of trial time spent on it. This also accounts for differences in trial duration.

To identify the best and worst touch actions for conveying each cued message, for each touch action, we calculated the proportion of time it appeared in all correct trials minus all incorrect trials for a given cue. This score was then used to rank the touch actions for each cue. We then selected the top four touch actions (or all actions that appeared more in correct than incorrect trials, if there were fewer than four i.e. with a positive score), and the bottom four touch actions (or all with a negative score if there were fewer than four).

Hand-tracking

In experiment 4, the physical attributes of standardized touch gestures from two expert senders were measured and characterized using a motion tracking system (Hauser et al., 2019). Measurements were taken via custom software utilizing a LeapMotion camera system (Leap

328 Motion, San Francisco, CA) to track the sender's hands and a Flock of Birds 6-DOF sensor
329 system (Trakstar and Model 800 sensors, Ascension, Shelburne, VT) to track the receiver's
330 forearm. Six contact metrics were considered: 1) velocity of the sender's hand normal to the
331 receiver's arm 2) velocity of the sender's hand tangential to the receiver's arm, 3) the total
332 contact area between the sender's hand and the receiver's skin, 4) the percentage of the sender's
333 palm area contacting the receiver's skin, 5) the number of the sender's fingers contacting the
334 receiver, and 6) the proportion of time in which the sender's palm was in contact with the
335 receiver. To compare across gestures, mean values for each contact metric were normalized
336 between 0 to 1 based on the population standard deviation.

337 Data Availability

338 Datasets are available on figshare (<https://doi.org/10.6084/m9.figshare.c.5630842.v2>), and
339 analysis scripts and materials are available on github
340 (<https://github.com/SDAMcIntyre/touchcomm-psci>).

341 Results

342 Touch communication within close relationships

343 In two experiments involving pairs in close relationships, we found that the participants assigned
344 to the role of receiver were able to interpret the gestures based on touch alone, and select the
345 correct message at well above the chance rate (Figure 1), despite neither participant receiving
346 any feedback or training. Additionally, the correct response was the most popular one, for every
347 cue (Figure 1B, C & E), although this was not true for all individuals (Figure S1). This
348 demonstrates that social touch messages are readily communicated within emotionally close
349 pairs, consistent with previous reports (Hertenstein et al., 2009; Hertenstein, Keltner, et al., 2006;
350 McIntyre et al., 2019).

Figure 1. Touch communication between people in a close relationship (intuitive touch). Performance was better than chance for every cue, demonstrated in two experiments. Touch cues and responses are abbreviated: Att (attention), Lov (love), Hap (happiness), Cal (calming), Sad (sadness) and Gra (gratitude), Oth (other), Tim (timeout). (A) Illustration of the experimental setup. The sender was presented with a cue, and then touched the receiver to communicate the message. The receiver entered their responses in a separate interface. The participants could not see each others' monitors or faces. (B) Group-level confusion matrix for the communication task in the roles (sender and receiver) initially assigned; experiment 1 (E1). Total numbers of trials pooled over participants are shown inside the

squares, and the shading gives the percentage for that cue. (C) Group-level confusion matrix after the pairs swapped roles, experiment 1 (E1). (D) F1 performance score (min = 0, max = 1; given by the harmonic mean of Recall and Precision) for experiment 1. F1 score for each pair and cue is shown as filled circles. Performance varied significantly by cue ($\chi^2(5) = 432.02$, $p < .001$, mixed effects model, see text), was significantly better after swapping roles ($\chi^2(1) = 39.64$, $p < .001$), and this effect varied with the cued word ($\chi^2(5) = 24.20$, $p < .001$). The model estimates and 95% confidence interval are also shown. Chance-level performance ($F1 = 0.29$) is shown as a dashed line. (E) Group-level confusion matrix from a second experiment, in which participants did not swap roles. (F) F1 performance scores, model estimates and 95% confidence intervals for experiment 2. Performance varied significantly by cue ($\chi^2(5) = 1911.80$, $p < .001$).

To evaluate touch communication performance, we used the F1 metric, which reflects performance that minimizes both misses and false positives. The chance rate was set at 0.29, which is the maximum possible F1 score for a single cue when giving identical answers on all trials (see Data Analysis for further details). In the first experiment (Figure 1A-D), overall performance was significantly better than chance (*Estimated Marginal Mean F1 score* = 0.59, 95% CI = 0.49, 0.68, $z = 18.00$, $p < .001$, mixed effects model, see Data Analysis for model specification), as was performance for every individual cue (Figure 1D, all $ps < .001$, Holm correction). In this experiment only, the pairs swapped roles half-way through the testing session so that the sender became the receiver and vice versa. Swapping roles significantly improved identification of happiness, calming and gratitude (attention: *Odds Ratio* = 0.81, 95% CI = 0.58, 1.12, z ratio = -1.32, $p = .190$; love: *OR* = 0.89, 95% CI = 0.68, 1.17, $z = -0.84$, $p = .403$; happiness: *OR* = 0.60, 95% CI = 0.45, 0.80, z ratio = -3.4, $p < .001$; calming: *OR* = 0.47, 95% CI = 0.36, 0.62, z ratio = -5.44, $p < .001$; sadness: *OR* = 1.01, 95% CI = 0.68, 1.17, z ratio = -0.836, $p = .403$; gratitude: *OR* = 0.52, 95% CI = 0.39, 0.68, z ratio = -4.7, $p < .001$; post-hoc pairwise comparisons with Holm correction).

385 In a second experiment (Figure 1E-F), the communication task was performed with the receiver
386 in an MRI scanner (data presented in a separate manuscript), and the pairs did not swap roles.
387 Similar to experiment 1, overall performance in experiment 2 was significantly better than
388 chance ($EMM F1$ score = 0.58, 95% CI = 0.47, 0.68, z = 17.8, p < .001), as was performance for
389 every individual cue (Figure 1F, all ps < .001, Holm correction).

390 Facial expressions accompanying touch communication

391 In order to measure facial expressions during touch communication within close relationships, in
392 experiment 1 we recorded facial muscle activity in the zygomatic (smiling) and the corrugator
393 (frowning) muscles, in both the sender and the receiver, using facial EMG (fEMG; Figure 2). For
394 the outcome measure, we used the participant level z-score of the activity measured on each
395 muscle, and took the difference in z-score measured during the first four seconds of touch
396 relative to a baseline period preceding the touch (see Methods, Figure S2).

Figure 2. The role of facial expressions in touch communication. Cue abbreviations as in Figure 1. (A) Mean facial EMG activity of the zygomaticus muscle during the first 4 seconds of touch during the touch communication task, as participant-level z-scores during the touch, relative to baseline (y axis = 0). Data from a total of 939 (sender) and 954 (receiver) trials after artifact rejection (see Methods). The y-axis is on a pseudo log scale to emphasize differences between the different cues rather than individual data points. Circles show the average for each participant-cue combination. Cross-bars give the estimated marginal mean and 95% CI for each participant role and cue. (B) Activity of the corrugator muscle, format as in (A). Data from a total of 924 (sender) and 935 (receiver) trials after artifact rejection. (C) Performance of a random forest classifier on the facial muscle activity (data from both muscles, see Methods) of the sender to predict the cue. (D) Performance of a random forest classifier on the facial muscle activity of the receiver to predict the cue. (E) The receivers' accuracy in interpreting the messages was not significantly positively correlated with either classifier's performance.

Although the senders and receivers could not see each other's faces (Figure 1A), we found that both the senders' zygomatic and corrugator activity, and the receivers' zygomatic activity varied according to the cued message that was being communicated through touch.

Mixed-effects models (see Data Analysis for full specification) revealed that the senders' zygomatic activity during touch was significantly greater than baseline (EMM = 0.19, 95% CI = 0.10, 0.28, $t(28) = 4.13$, $p < .001$), and varied with the cue ($F(5,906) = 49.69$, $p < .001$, model estimates and CIs shown as crossbars, Figure 2A). The receivers' zygomatic activity during touch was not overall significantly greater than baseline (EMM = 0.03, 95% CI = -0.03, 0.10, $t(28) = 1.02$, $p = .316$), but did vary significantly with the cue ($F(5,920) = 7.04$, $p < .001$, Figure 2A).

The senders' overall corrugator activity was not significantly different during touch compared to baseline (EMM = 0.06, 95% CI = -0.04, 0.157, $t(28) = 1.14$, $p = .264$), but did vary significantly with cue ($F(5,891) = 8.58$, $p < .001$, Figure 2B). The receivers overall corrugator activity was not significantly different during touch compared to baseline (EMM = -0.04, 95% CI = -0.10, 0.03, $t(28) = -1.15$, $p = .262$), and nor did it vary with cue ($F(5,901) = 1.50$, $p = .188$, Figure 2B).

We predicted that if the variations in the senders' facial expressions were related to their capacity to convey social messages, the facial muscle activity of the sender should be related to the successful communication of messages. Similarly, if the variations in the receivers' facial expressions reflected their ability to decode the touch messages, their facial muscle activity would also be related to performance on the communication task. To test this, we applied machine learning methods to train random forest classifiers on the facial muscle activity of the senders and the receivers separately, to predict which message was cued (see Methods). When the classifier was trained on either the senders' or the receivers' facial muscle activity, it could predict the cued message significantly better than chance (chance hit rate 16.7%; *sender*: 24.8% $\pm$ 5.9% standard deviation across the 10-fold cross validation procedure; $p < .001$, $n = 914$ trials with data available from both muscles, Figure 2C; *receiver*: 21.0% $\pm$ 4.4% SD; $p < .05$, $n = 931$

trials, Figure 2D). Contrary to our prediction, neither classifier's performance significantly correlated with performance on the touch communication task (*sender*: $r = -0.05$, 95% CI = -0.41, 0.33, $t(27) = -0.24$, $p = 0.8153$; *receiver*: $r = -0.19$, 95% CI = -0.52, 0.19, $t(27) = -1.02$, $p = 0.3166$; including only those individuals with classifier data for at least 10 trials; Figure 2E).

Development of standardized touch gestures

To characterize the intuitive touch gestures, we video-recorded the touch communication task in the same experiment in which we recorded fEMG activity (experiment 1). The touching activity was coded by research assistants for location, intensity, and type of touch from a list of descriptors adapted from (Hertenstein, Keltner, et al., 2006). We found that successful strategies for touch communication in a close relationship shared common features across senders (Figure 3). For attention, the best features were moderate tapping and shaking. For calming it was light holding at multiple locations on the arm, as well as moderately stroking the whole or lightly stroking part of the arm. Gratitude was associated with light stroking or holding, or squeezing the arm. Happiness was best conveyed by light tapping across the whole arm. Love was successfully signaled by light stroking across the whole arm. Successful communication of sadness was most strongly associated with lightly holding or stroking one part of the arm. Touching the hand and using high intensity were generally unsuccessful strategies.

Figure 3. Location, intensity, and touch descriptors that best discriminated correct and incorrect interpretation of the messages. Density plots of the touch durations for each cue are shown above the panels. Because the overall touch duration for different cues varied, time for each combination of features was calculated as a percentage of the total touching time for each cue (see Methods for more details). The top panels show the best combinations of touch features, up to four for each cue, that were observed most in the correct trials (time in correct trials minus time in incorrect trials). The bottom panels show the worst combinations, that were observed most in the incorrect trials (time in incorrect trials minus time in correct trials). The size of the circle reflects the difference in touch duration in correct vs. incorrect trials. Intensity is visualized by color. The y-axis shows the touch locations (the top line in which the whole arm is shaded indicates touches that were applied to at least two individual locations).

To validate if our characterizations of intuitive touch meaningfully reflect the features of touches that are important for communicating emotional cues, we developed standardized touch gestures (Supplementary Movies S1-S6). These were made up of the common features we observed in successful touch communication, and we avoided features found in unsuccessful communication (Figure 3). When delivered by three trained experimenters to naïve strangers in two experiments

(Figure 4), overall identification of the touch messages was significantly better than chance (experiment 3: *EMM F1 score* = 0.73, 95% *CI* = 0.62, 0.81, $z = 7.57$, $p < .001$; experiment 4: *EMM F1 score* = 0.65, 95% *CI* = 0.59, 0.71, $z = 19.20$, $p < .001$; mixed effects models, see Data Analysis for model specification), as was performance for every individual cue (experiment 3: all $ps < .001$, Holm correction; experiment 4: all $ps \leq 0.02$, Holm correction). As in the intuitive touch task, the correct response was generally the most popular one (except experiment 4 gratitude, which was more often labeled calming), with individuals showing more variation (Figure S3).

480

481 *Figure 4. Touch communication between a trained expert sender and a naïve stranger receiver*
 482 *(standardized touch). Performance was better than chance for every cue, demonstrated in two*
 483 *experiments. Cue abbreviations as in Figure 1. (A) Group-level confusion matrix for the communication*
 484 *task involving expert sender 1; experiment 3. Numbers of trials are shown inside the squares, and the*
 485 *shading gives the percentage for that cue. (B) F1 performance score (min = 0, max = 1) for experiment 3.*
 486 *E3 Performance varied significantly by cue ($\chi^2(5) = 1209.80$, $p < .001$, parametric bootstrap). F1 score*
 487 *for each pair and cue is shown, as well as the model estimate and 95% confidence interval from the*
 488 *mixed effects model (see text). Chance-level performance (F1 = 0.29) is shown as a dashed line. (C)*
 489 *Group-level confusion matrix from a second experiment with standardized touches (experiment 4), in*
 490 *which participants interpreted the touch messages delivered by both expert senders 2 and 3. (D) F1*
 491 *performance scores, for experiment 4. E4 Performance varied significantly by cue ($\chi^2(5) = 1793.60$, $p <$*
 492 *.001, parametric bootstrap). F1 score for each pair and cue is shown, as well as the model estimate and*
 493 *95% confidence interval from the mixed effects model (see text).*

Hand tracking using a 3D motion-tracking system (Hauser et al., 2019) was used to characterize the different gestures in more detail, breaking them down into physical primitives (Figure 5A, S4 and S5). Both attention and happiness were characterized by high normal velocity, a small contact area and brief duration, but happiness had a high tangential velocity, whereas attention involved almost no lateral movement. Love and calming were both characterized by slow tangential movement; but compared to calming, love had a longer contact duration, a smaller overall contact area, and a higher ratio of finger to palm contact. Sadness was static with a large contact area and long contact duration. Gratitude involved slow normal and tangential movements with moderate contact area and duration.

We directly compared the standardized touches performed by experts to the intuitive touches performed by someone in a close relationship in a separate analysis (Figure 5B). We found that identification of the standardized gestures was similar to or even slightly better than the intuitive touches ($\chi^2(1) = 4.52, p = 0.027$, parametric bootstrap, mixed effects model, see Data Analysis for full model specification). Specifically, standardized touches produced significantly better recognition than intuitive touches for love, happiness and calming (attention: $OR = 0.80, 95\% CI = 0.52, 1.22, z\ ratio = -1.04, p = .301$; calming: $OR = 1.73, 95\% CI = 1.1, 2.6, z\ ratio = 2.58, p = .010$; gratitude: $OR = 0.76, 95\% CI = 0.50, 1.15, z\ ratio = -1.288, p = .198$; happiness: $OR = 2.32, z\ ratio = 3.94, p < .001$; love: $OR = 4.44, 95\% CI = 2.92, 6.76, z\ ratio = 6.97, p < 0.0001$; sadness: $OR = 1.35, 95\% CI = 0.89, 2.04, z\ ratio = 1.40, p = .161$; post-hoc pairwise comparisons with Holm correction). Furthermore, without feedback, the receivers were able to quickly learn the meaning of the gestures and reached a stable performance level after only 10-12 presentations (Figure 5C).

Figure 5. Characterization and evaluation of the standardized touches. Abbreviations as in Figure 1. (A) Physical features of the standardized touches delivered by trained experimenters and measured using an automated hand-tracking system (experiment 4, experts 2 and 3). Mean values for each contact metric were normalized between 0 and 1 based on the population standard deviation. (B) Model estimates of F1 performance score, and 95% CIs from a mixed-effects model comparing intuitive and standardized touch strategies. Performance varied significantly by cue ($\chi^2(5) = 4452.44$, $p = 0.001$, parametric bootstrap), and there was a significant interaction between touch type and cue ($\chi^2(5) = 697.12$, $p = 0.001$, parametric bootstrap). (C) The standardized cues were learned quickly, with performance reaching a plateau within 10-12 presentations for most cues, without feedback. The lines were fit with a loess function with a span of 1, the shaded area is the 95% CI based on the standard error (combined data from experiments 3 and 4).

Discussion

529 We have identified touch expressions for which the social and emotional content are broadly
530 understood between strangers, at least within one cultural context. Indeed, skillful strangers can
531 communicate emotional touch messages as effectively or better than people in close
532 relationships. We have ruled out a large role for an idiosyncratic touch language developed
533 within couples or other close relationships in touch communication efficacy. Communication
534 performance without feedback was well above chance with our standardized touch expressions
535 reflecting their basis in real interpersonal touch interactions, and a common understanding.
536 However, our study recruited adults living in Sweden, and an important open question is whether
537 the standardized touch expressions are universally understood across cultural context.

538 That people can understand social and emotional touch messages confirms earlier reports (App et
539 al., 2011; Hertenstein et al., 2009; Hertenstein, Keltner, et al., 2006; Kirsch et al., 2018). That
540 strangers are as good or better at communicating via touch than people in a close relationship
541 provides an apparent contrast with earlier work showing that romantic couples communicate
542 more effectively than stranger pairs (Thompson & Hampton, 2011). We reconcile this by
543 considering that the earlier work used untrained strangers, while we trained our experimenters to
544 use effective touch strategies using clear and distinct touch gestures. This training may
545 compensate for a greater reluctance to touch a stranger compared to someone close (Suvilehto et
546 al., 2015, 2019).

547 We went beyond previous studies' (Gaus et al., 2015; Hertenstein et al., 2009; Hertenstein,
548 Keltner, et al., 2006; Jung et al., 2015; Masson & Op de Beeck, 2018; Supratman et al., 2020)
549 efforts to characterize the physical features of touch communication. We did this by first
550 evaluating their contribution to communication efficacy, and then validating this by showing that
551 standardized touch strategies based on the features identified as effective, were indeed capable of

conveying the intended message. Additionally, we used a 3D hand-tracking approach to obtain quantitative descriptors of the standardized touch expressions including normal and tangential velocity, contact area and duration, and palm and finger contact.

A previous study evaluated the relationship between motion energy obtained from filmed interpersonal touch interactions and observers' judgments of their valence and arousal (Masson & Op de Beeck, 2018). More positively viewed interactions tend to have lower motion energy, while more (emotionally) arousing interactions have higher motion energy. Our results are consistent with this finding, with the highest measured velocities observed in our attention and happiness expressions, which are likely to be relatively high arousal. Interestingly, these are the same two cues that in the receiver provoked a significant increase in zygomatic activity, which has been associated with high arousal positive stimuli (Fujimura et al., 2010). Additionally, our sadness expression, being the only negative valence message, had near zero velocity.

While measuring motion energy is quantitative and informative, we have shown that more detailed physical measurements can further discriminate specific touch messages, e.g., happiness and attention had similar normal velocities but very different tangential velocities, while contact duration and area discriminated love and calming, which had similar tangential velocities. This is consistent with studies of human-delivered touch to pressure sensor surfaces (Gaus et al., 2015; Supratman et al., 2020) and robot-delivered touch to humans (Teyssier et al., 2020) showing that a variety of contact area and motion dynamics measures are required to distinguish different touch actions.

In our touch communication task, the sender and receiver could not see each other's expressions, but we asked if either role's facial expressions might interact with touch communication. The senders' zygomatic and corrugator activity, as well as the receivers' zygomatic activity varied

575 according to the touch message. However, when we looked for a relationship between facial
576 muscle activity and communication success on an individual level, we did not find it. This
577 suggests that the varying facial muscle activity may simply reflect the participants' adoption of
578 an existing set of strategies for communicating emotion that would normally involve both touch
579 and facial expression. An alternative explanation for these findings is that some aspects of facial
580 muscle activity that we did not measure are relevant to touch communication, or that there is a
581 weak relationship (small effect size) that we failed to detect.

582 The senders showed increased zygomatic activity when communicating attention, happiness and
583 gratitude, suggesting that expressing these messages may be accompanied by smiling. The
584 sender also showed increased corrugator activity when communicating happiness, possibly due
585 to high arousal produced by its high intensity (Figure 3) and speed (Figure 5). The receivers also
586 showed increased zygomatic activity when feeling the touch expressions for attention and
587 happiness, but not gratitude. The relatively high intensity and speed of the attention and
588 happiness may have provoked a positive emotional response from the receiver (Fujimura et al.,
589 2010). The result contrasts with previously observed increased zygomatic activity in response to
590 a gentle stroking with a brush that most resembled our calming expression (Pawling et al., 2017).
591 The touch evoked no significant changes in the corrugator activity of the receivers, in contrast to
592 previous studies showing reduced corrugator activity (Mayo et al., 2018; Ree et al., 2020) in
593 response to pleasant touch.

594 Our standardized touches closely resemble authentic interpersonal touch, while being optimized
595 for communicating specific messages. This is because they were developed based on the
596 successful communication strategies that people in close relationships used when given minimal
597 instructions. While we cued a specific message to communicate, and limited the area of the body

that could be touched, the participants were otherwise free to choose their own touch strategy. Some previous studies on touch communication systematically investigated different types of messages. For example, App et al. (2011) investigated which non-verbal communication channels are used for messages that correspond to different social functions (status-conveying, survival-focused and intimacy-focused). Kirsch et al. (2018) investigated how the same touches were interpreted differently if the receivers were given different tasks – either interpreting the emotion or the intention of the person performing the touches. In our study, we did not try to systematically vary details of the messages to be communicated because we did not have any specific hypotheses relating to them. Rather, our goal was simply to capture a variety of touch behaviors. Similarly, we did not control the exact type of relationship or demographics of our participants (Hertenstein et al., 2009; Hertenstein, Keltner, et al., 2006; Thompson & Hampton, 2011), the investigation of which would have required different sample size considerations.

The interpretation of touch messages is likely to be influenced by a large number of contextual factors (Cekaite & Bergnehr, 2018; Weiss, 1986). We found that when pairs swapped roles, performance improved (Figure 1B-D). Experiencing multiple roles may have aided communication in a way that is similar to more interactive, natural contexts. One example of a real-world situation that has similar contextual information to our communication task is text communication. In principle, text alone can convey all information, analogous to speech. However, the widespread use of emoji to convey facial expressions illustrates that there is a clear desire to use analogs of non-verbal communication. Emoji rely on a pre-existing broad consensus about the mapping between the visual elements of a facial expression and an emotional meaning. Similarly, our standardized touches did not require specific training or any feedback, but were

able to capitalize on a pre-existing broad understanding, while also benefiting from additional contextual information.

Conclusions

When people in a close relationship engaged in emotional touch communication, the senders intuitively produced distinct gestures to effectively communicate different messages of attention, love, happiness, calming, sadness, and gratitude. The touch messages were associated with the senders' facial expressions, but we found no evidence that this was related to the ability of the receivers to correctly interpret the touch message. In contrast, choosing the right touch strategies with appropriate physical features were sufficient for effective communication. We demonstrated this with our set of tactile standardized gestures delivered to naïve strangers, which were identified even more successfully than the intuitive gestures delivered within the context of a close relationship. We have thus presented a lexicon of gestures, with distinct physical characteristics, that can be used for social communication to enrich emotional content. These findings inform the development and improvement of interpersonal communication mediated by haptic interfaces. It could also inform development of training for people in any context in which it is desirable that communication is enhanced and emotional touch communication is appropriate. It may also provide a useful tool for exploring social differences associated with psychiatric disorders.

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Author contributions

Conceptualization SM, RB, GN, SSN, AI, EAL, FA, GJG, HO; Methodology SM, SCH, RB, AM, PMI, GN, GJG, HO; Software SM, SCH, AK, GJG; Investigation SM, AK, RB, AM, PMI, LH; Formal Analysis SM, SCH, AK; Writing – Original draft SM, RB, AM, HO; Writing – Review & Editing SM, SCH, AK, RB, AM, PMI, LH, GN, SSN, AI, EAL, FA, GJG, HO

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The language of social touch is intuitive and quantifiable

Supplementary Text

Questionnaires

In experiments 1 – 3, participants answered questionnaires at the beginning of the experimental session. Data from experiment 2 are reported in a separate manuscript, and data from experiments 1 and 3 are given here. Results from all three experiments were similar. Participants in both experiments 1 and 3 answered the ‘Social Touch Questionnaire’ (STQ) a 20-item validated questionnaire that assesses the personal attitude towards social situations involving touch (Wilhelm et al., 2001). In experiment 1, participants were also asked to define the nature of their relationship, which was categorized as romantic, friends or family. Participants were also asked to rate the degree of emotional closeness.

Social Touch Questionnaire

The Social Touch Questionnaire (STQ) has a minimum score of 0, indicating relative comfort with touch, and a maximum of 80, indicating relative discomfort with touch. The overall mean score in experiment 1 was 29.0 (SD = 9.6). STQ scores did not significantly differ between our female (M = 31.2, SD = 9.3) and male (M = 27.1, SD = 9.7) participants (95% CI = -2.8, 11.1, $t(30) = 1.2$, $p = 0.231$). There was no significant correlation between touch communication performance and STQ scores of the receiver ($r = -0.02$, CI = -0.38, 0.32, $p = 0.923$), or of the sender ($r = 0.12$, CI = -0.23, 0.46, $p = 0.511$). Similarly, in experiment 3, performance on the

806 touch communication task did not significantly correlate with STQ scores (receiver: $r = 0.06$, $p =$
807 0.799).

808 Relationship closeness

809 In Experiment 1, participants rated the relationship with their partner for closeness, on a scale of
810 1 – 4. Because of the small range in scores, we treated closeness as a categorical variable.

811 Overall touch communication performance was not significantly affected by the closeness score
812 provided by the participants (receiver: $F(2,28) = 0.7$, $p = 0.493$, $CI: \pm 0.5$; sender: $F(2,28) = 1.3$, p
813 $= 0.299$, $CI: \pm 0.5$).

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822   *Figure S1. Individual confusion matrices for the intuitive touch communication task between people in a*

823   *close personal relationship. Each panel shows the confusion matrix for one participant in the receiver*

824   *role. Panels are arranged in order of overall performance. A = attention, L = love, H = happiness, C =*

825   *calming, S = sadness, G = gratitude, O = other, T = timeout.*

Figure S2. Facial EMG over time during the touch communication task. Data are in 100ms bins, shaded area = 95% CI based on 1000 bootstrapped samples, mid-points are the mean. 0 sec = touch onset. Data for each cued word are plotted until the time point at which 75% of trials have finished.

Figure S3. Individual confusion matrices for the expert touch communication task where the sender was a trained experimenter unknown to the receiver. Each panel shows the confusion matrix for one participant in the receiver role. Panels are arranged in order of overall performance. A= attention, L = love, H = happiness, C = calming, S = sadness, G = gratitude, O = other.

Figure S4. Separate representation of the physical features of the standardized touches for two trained experimenters, measured using an automated hand-tracking system (experiment 4). Mean values for each contact metric were normalized between 0 and 1 based on the population standard deviation.

calming

attention

sadness

gratitude

love

happiness

841 *Figure S5. Time-slice of standardized gestures from hand-tracking system.*

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843 *Movie S1. Video example of the standardized attention gesture.*

844 *Movie S2. Video example of the standardized love gesture.*

845 *Movie S3. Video example of the standardized happiness gesture.*

846 *Movie S4. Video example of the standardized calming gesture.*

847 *Movie S5. Video example of the standardized sadness gesture.*

848 *Movie S6. Video example of the standardized gratitude gesture.*

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