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User-defined gestures for mediated social touch on touchscreens

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Abstract
Mediated social touch is a new form of remote communication. Some researchers designed prototypes to deliver mediated social touch for mobile devices. However, there lacks a comprehensive analysis of the user-defined gestures of mediated social touch on touchscreens of mobile devices. We conducted an elicitation study for 24 social touch gestures on the touchscreen of smartphones and recorded physical parameters. We developed a user-defined gesture set considering physical properties and context. We provided classifications based on the movement forms. We found that social touch gestures with shorter duration were easier for participants to perform; participants were inclined to use social touch with an easier gesture more often. Participants were more likely to express happy or sad expressions rather than neutral emotions. Based on the findings, we discussed the implications for mediated social touch technology and its application on touchscreens.

Keywords Mediated social touch · Mobile devices · Touchscreens · User-defined gestures

1 Introduction

Remote communication between people is popular. Rantala et al. [1] mention that visual and audio channels are the main channels for traditionally remote communication. Besides these two channels, mediated social touch would be a new form of remote communication [1].

Mediated social touch means "the ability of one actor to touch another actor over a distance by means of tactile or kinesthetic feedback technology" [2]. As advanced haptic actuators are embedded in most mobile devices [3], there is a possibility to make mediated social touch become more active in interaction with mobile devices in remote communication [1]. For example, the Taptic Engine in iPhones (since iPhone 7) could provide various physical effects with haptic feedback [4].

Some mediated social touch has been designed for mobile devices. Some researchers designed prototypes (i.e., POKE [5], CheekTouch [6, 7], and ForcePhone [8]) for mobile devices to deliver mediated social touch (e.g., poke, pat, slap, tickle, and kiss) via vibrations. Hemmert et al. [9] designed three mobile phone–shaped and –sized prototypes with sensors and actuators to deliver grasping, kissing, and whispering. Furukawa et al. [10] proposed a "Shared Tactile Interface" (KUSUGURI) to send the bidirectional tickling sensation. Rantala et al. [1] designed a mobile device and demonstrated that vibrotactile stimulations that imitate human touch could convey intended emotions in remote communication.

However, these researches ([5–8]) mainly focused on the context of phone calls (with phones on the ear). There is a lack of context with phones on the hands (e.g., texting or video calling). In the context of texting or video calling, users would hold the phone on hands with no big movements. On the other hand, these researches mainly provided novel prototypes ([1, 5–10]) without an understanding of physical properties [11] of mediated social touch, such as pressure and duration. Yohanan and MacLean [11] mentioned physical properties included common points of contact as well as duration and intensity of gestures. Physical properties are essential for applying tactile or kinesthetic feedback technology. For example, suppose we deliver mediated social touch via tactile feedback. In that case, the perceived intensity and duration of tactile feedback could be designed based on the pressure and duration of specific mediated social touch [8, 12].

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In this study, the overall research aim is to provide guidelines to design mediated social touch based on user-defined gestures and related data of physical properties in the context of texting or video calling.

To get a comprehensive understanding of more mediated social touch, we choose 24 social touch gestures from Touch Dictionary [11]. This Touch Dictionary was extracted from human-animal interaction, human–human touch, and human–human affective touch [11]. Frequently, gestures from different sources overlapped in kind but not name [11]. It presented a relatively complete picture of social touch that could exist between humans. So it was efficient to choose social touch gestures from this Touch Dictionary [11].

We focus on the mediated interaction between humans via touchscreens of mobile devices because the context in remote communication we consider is with mobile devices on hands (e.g., texting or video calling). We explore the user-defined gestures of mediated social touch on the touchscreen and related physical properties.

We apply the elicitation study [13] to explore the user-defined gestures of mediated social touch on the touchscreen and gain related physical properties. The elicitation study is beneficial for exploring surface gestures that people make in natural interactions [14] because gesture-based natural interactions provide a higher likelihood to design interfaces that are easy to perform and remember [15]. Many researchers have conducted the elicitation study to explore related gesture sets on mobile devices or touchscreens ([13, 15–22]).

The research questions are as follows:

- What are the user-defined gestures for mediated social touch on touchscreens?
- What are the physical properties of mediated social touch on touchscreens?
- What are the implications for designing mediated social touch for mobile devices or touchscreens?

2 Related work

2.1 Elicitation studies for mobile devices and touchscreens

As many sensors have been embedded in mobile devices, gesture recognition on mobile devices to invoke commands has become possible [16]. User-defined gestures are important in the mobile computing paradigm [16].

Many researchers have applied elicitation studies to explore user-defined gestures for mobile devices and touchscreens. Wobbrock et al. [13] conducted an elicitation study to design tabletop gestures. They demonstrated that consensus existed on parameters of movements and mappings of motion gestures onto commands for surface computing [13]. They also developed a taxonomy for motion gestures to specify a user-defined gesture set. Tu et al. [17] explored user-defined gestures to perform interactive tasks in three common tablet-holding postures, and they compared the effects in different holding postures. Findlater et al. [18] provided a gesture set that included multi-touch and single-touch gestures for commonly used non-alphanumeric text input. They found that using gestures for non-alphanumeric inputs was no slower than using keys. Kurdyukova et al. [19] explored iPad gestures that users naturally performed for data transfer. Three transfers were two iPads, an iPad and a tabletop, and an iPad and a public display. Three modalities were checked: multi-touch gestures, spatial gestures, and direct contact gestures. They indicated how the user would choose modalities and gesture types in a different context [19].

Some researchers studied user-defined gestures for more than the front screen of mobile devices. Shimon et al. [20] applied an elicitation study to explore user-defined gestures for smartphone commands and identify their criteria for using back-of-device gestures. Wu and Yang [21] explored user-defined multi-finger gestures for game tasks on a dual-screen mobile device (both front and rear screens). Liang et al. [22] explored user-defined gestures to provide information to users through a dual-surface concept device (both front and back surfaces). They indicated a consensus existed among gestures for choice of sensory, multi-touch, and dual-surface input.

Some researchers compared the user-defined gestures among different age groups. Rust et al. [23] studied user-defined gestures from children for touchscreen tabletop interaction. They compared the difference between adults and children. The results showed that adults and children created similar gestures. The results provided a basis for future user-defined gesture studies with children.

From above, we found that the following two points were important for considering:

1. *Function*. There is a gap in exploring user-defined gestures for social context. Most gestures were defined for manipulating mobile devices, such as commands for interaction with touchscreens. However, since social communication is, after all, among humans, not between a human and a computer, the guideline for user-defined gestures for social context may differ from that of function commands. We should consider the characteristics of human communication when exploring user-defined gestures for mediated social touch.
2. *Context*. Different contexts may lead to different user-defined gestures. For example, Tu et al. [17] compared user-defined gestures in three holding postures of a tablet. For some commands, user-defined gestures were significantly different between different holding postures.

We should not mix different contexts when exploring user-defined gestures.

2.2 Mediated social touch on mobile devices and touchscreens

User-defined touch gestures for mediated social touch can be used as input on mobile devices and touchscreens. Mediated social touch has been explored in different applications.

Researchers developed prototypes to create a real-time mediated social touch on mobile devices. Park et al. [5] presented Poke—a prototype which was a remote touch technique through an inflatable surface. The inflatable surface was attached to the mobile device. It was designed for delivering pleasant emotional touches over interpersonal mobile communications. The study also found it was possible to send "poke," "shake," and "pat" through this inflatable surface during a typical phone call. Park et al. [6, 7] also designed a pair of CheekTouch prototypes. Each prototype had a multi-touchscreen. Users could deliver touch through the vibrotactile display. Hemmert et al. [9] designed three mobile-like prototypes embedded with sensors and actuators to deliver grasping, kissing, and whispering for mobile phones. Hoggan et al. [8] provided ForcePhone—a mobile synchronous haptic communication system. Users could squeeze the side of the device during phone calls. The pressure would be transferred to the mapping vibrations on another user's device. Furukawa et al. [10] proposed a method of "Shared Tactile Interface" (KUSUGURI), which could share a body part with another user at a distance. It could send the bidirectional tickling sensation. Rantala et al. [1] designed a mobile device to show that vibrotactile stimulation that imitated human touch could convey intended emotions from one person to another.

From above, we found that the following three points were important for considering:

1. *Context*. So far, the context of the work was during a phone call (with the phone on the ear). There is a gap in another context in remote communication with the phone on the hand, that is, texting or video calling.
2. *Touch types*. Not too many social touch gestures were considered in the above researches. Researchers developed prototypes to deliver several simple touch gestures for mobile devices. It would be interesting to consider more social touch gestures in remote communication.
3. *Physical properties*. The physical properties of mediated social touch were underexplored. Most researchers designed prototypes to send real-time touch. For example, Rantala et al. [1] and Hoggan et al. [8] delivered touch via vibrotactile stimuli, which were transferred by input pressure. Users could feel the emotion or feelings by the vibrotactile stimuli. But users may not recognize the specific social touch. It would be interesting to explore the physical properties of specific social touch and for guidelines of mediated social touch.

In summary, the points that we would like to highlight in this study were:

- We will consider more social touch gestures. We will choose 24 social touch gestures from Touch Dictionary [11].
- The context will be having remote communication with mobile devices on the hand, not on the ear (e.g., texting or video calling).
- We will explore user-defined gestures for mediated social touch on the touchscreen and explore related physical properties.

3 Methods

This section presents an experiment conducted based on the elicitation study [13] to explore user-defined gestures for mediated social touch on touchscreens and obtain related physical properties.

3.1 Participants

We recruited 20 participants (7 males and 13 females) aged from 23 to 35 to perform social touch on the smartphone touchscreen. Based on [24], a sample size of 20 participants is efficient in related elicitation studies [13, 16]. We randomly recruited participants from the TU/e campus. Participants' majors included Civil Engineering, Industrial Design, Industrial Engineering, Petroleum Engineering, Supply Chain Management, Traffic Planning, and Management. All participants have experience of using smartphones and social media.

3.2 Selection of referents

We chose 24 social touch gestures (Grab, Hit, Hug, Kiss, Lift, Massage, Nuzzle, Pat, Pinch, Poke, Press, Pull, Push, Rock, Rub, Scratch, Shake, Slap, Squeeze, Stroke, Tap, Tickle, Toss, and Tremble) from the Touch Dictionary [11]. As mentioned in Part 1, this Touch Dictionary presented a relatively complete picture of social touch that could exist between humans [11]. So it was efficient to choose social touch gestures from this Touch Dictionary [11].

3.3 Apparatus

Social touch was performed on an LG V30 smartphone (Fig. 1). The smartphone could recognize 2D touch [25]. During the experiment, the smartphone was powered off to reduce the visual bias of graphical display and prevent smartphone feedback because of gestures [25]. Also, to reduce the complexity of the implementation, a pressure sensor (The FlexiForce™ A502, sensing area: 50.8 mm × 50.8 mm) was attached to the smartphone's touchscreen. The sensing area was efficient for the active regions defined by the thumb sweep of the radius [26]. The pressure sensor was connected to a computer through an Arduino microcontroller to read the value of pressure. A processing program was used to read and store the pressure values from Arduino's serial port. The pressure was read every 50 ms.

A video camera was mounted on a tripod, positioned in front of participants to record the gestures performed by them. For privacy, only the hands of the participants were video recorded during the experiment.

3.4 Procedure

We conducted an elicitation study based on [13]. First, a brief introduction to the purpose of the study was introduced to the participants. Questionnaires and consent forms were delivered to each participant before the experiment.

There were three main tasks in the study: performing social touch on the touchscreen, explaining the social touch they performed, and filling out the questionnaires.

Participants were asked to perform social touch on the touchscreen and try not to use the smartphone's movement for the purpose. Tilting, rotating, panning, and shaking the smartphone to represent social touch were not considered in this study. We only considered the 2D touchscreen because the target context in this study was sending mediated social touch with a phone on the hand (e.g., texting or video calling). It would not be convenient to shake a mobile device when having a video call with others.

We recorded the pressure and duration of the touch gestures for exploring user-defined gestures considering physical properties and context, and as the next step of future research, designing parameters for mediated social touch.

Participants were given the chosen social touch from Touch Dictionary [11]. Participants were asked to imagine that another person was in the 2D touchscreen and perform the social touch gestures. For example, in "Shake," participants were asked to imagine how to shake someone on the touchscreen. Participants performed social touch on the pressure sensor's sensing area on the test device for recording physical data. The order of the social touch gestures was randomized. The randomized order was obtained using the random function in Python and was presented to each participant on the paper questionnaire. During the experiment, each social touch was performed five times. When finished with one social touch, participants were asked to explain why they performed the social touch gesture like that and fill out the questionnaire about the social touch.

We collected emotion data in this study because touch communicates emotion [27, 28]. A 9-point scale about arousal and valence [29] was applied to report what participants felt the touch gesture conveys.

It could be inconvenient for users to perform a difficult gesture in a real application. So, we wanted to find the properties of

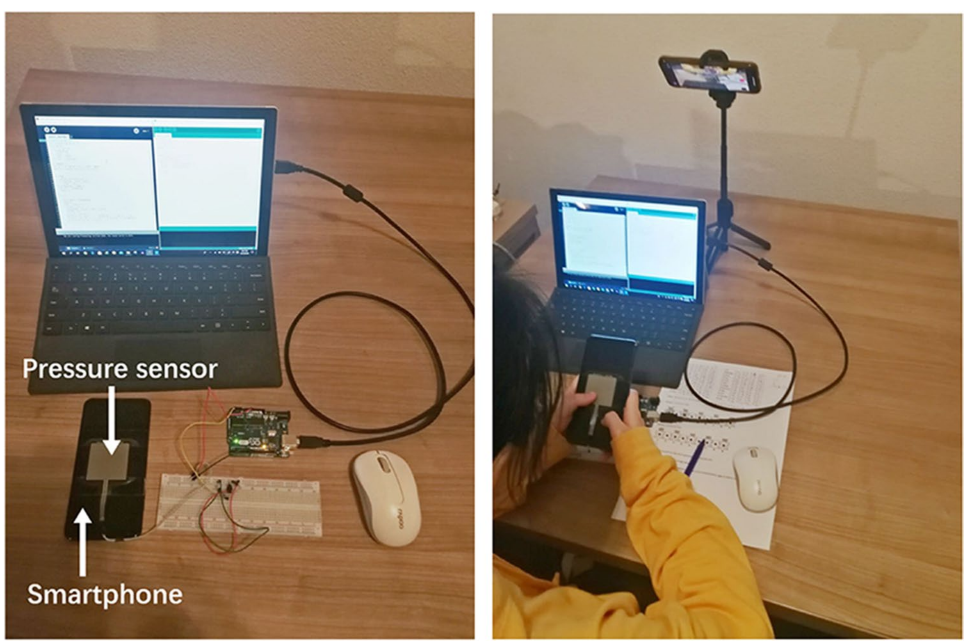

Fig. 1 Experiment setup. Left: installation. Right: test environment

easy gestures to guide future design and application. A 7-point Likert scale was applied to report the subject ratings of ease of performing ("I feel it is easy to perform this touch gestures on the touchscreen" from "strongly disagree" to "strongly agree") [16].

As we applied 24 social touch gestures, we wanted to find what mediated social touch that users frequently used to guide the future design focus. A 7-point Likert scale was applied to report the subject ratings of usage frequency ("I would often use this social touch if it existed in online social communication apps" from "never" to "very often") [16].

4 Results

Our results included a gesture classification based on all collected gestures, a user-defined gesture set considering context and physical properties, and a gesture classification based on movement form and subject ratings.

4.1 Gesture classifications on all collected gestures

We classified collected gestures along two dimensions: nature and cardinality (Table 1 and Fig. 2a). The nature dimension was from [13]. This dimension has been applied in many gesture elicitation studies [13, 14, 16, 17]. The cardinality dimension was from [17]. It was proposed to explore users' kinematic aspects for gesture interaction [17].

In the nature dimension, there are four types of gestures, namely physical, metaphorical, symbolic, and abstract gestures [13, 17].

Physical gestures would be the same between interaction with people in the real world (in 3D space) and interaction with touchscreens (on 2D touchscreens) because Tu et al. [17] indicate that physical gestures are meant to interact with the same way of using a physical motion on the object. The touchscreen could be regarded as the other user when performing physical gestures. Those social touch movements could be described similarly to those in the Touch Dictionary [11]. For example, "Poke," 19 out of 20 participants prodded the touchscreen with one fingertip.

Metaphorical gestures describe actions using something else to represent them [17]. For social touch, the metaphor has two dimensions: direction and movement. For direction, on the touchscreen, the upper area represents the further distance or higher location. The lower area represents the

Table 1 Classifications of tablet gesture

Nature	Physical		Gesture acts physically on objects
	Metaphorical		Gesture indicates a metaphor
	Symbolic		Gesture visually depicts a symbol
	Abstract		Gesture-referent mapping is arbitrary
Cardinality	Fingers	Atomic	Gesture is performed by one finger on one hand
		Compound	Gesture is performed by multi-fingers on one hand
		Parallel	Gesture is performed by multi-fingers on two hands
	Palm		Gesture is performed by the palm
	Fist		Gesture is performed by the fist

This table was adapted from [13] and [17]

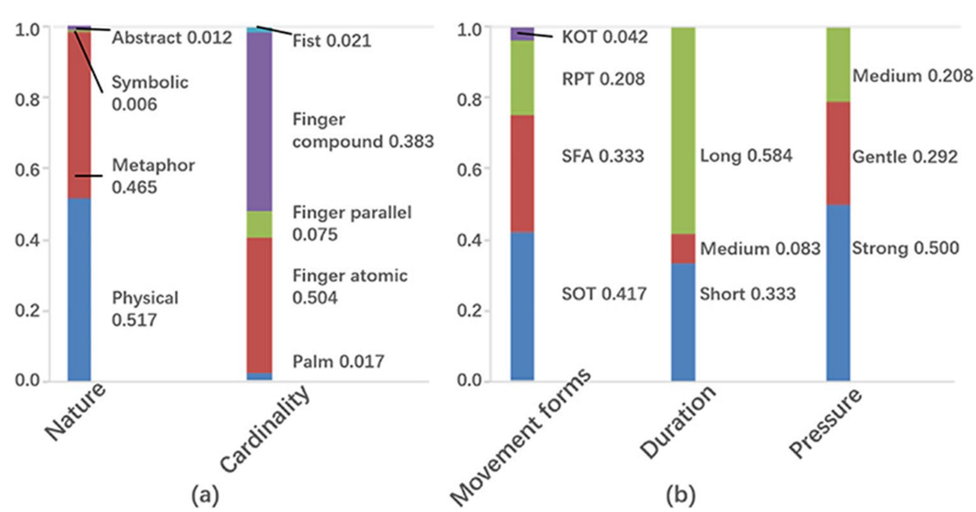

Fig. 2 **a** Gesture classifications based on all 480 collected gestures; **b** gesture classifications based on movement forms

closer distance or lower location. For example, "Pull," 14 out of 20 participants "Pull" someone on the touchscreen by swiping their fingers down. Nineteen participants swiped fingers up to represent "Lift" someone. For "Hug", 11 out of 20 participants moved two thumbs close together to represent two arms' movement embracing the other one. For movement, participants used similar gestures on the touchscreen to represent "shake" (19 out of 20), "rock" (16 out of 20), and "tremble" (19 out of 20). They moved their fingers on the touchscreen back and forth to represent the body movements.

Symbolic gestures are visual depictions [13, 17]. For example, P13 drew a heart shape to represent "Kiss" to show love.

Abstract gestures mean that the gesture-referent mapping is arbitrary [13]. For example, P12 used the right thumb to point the touchscreen one time as "Stroke."

In the origin cardinality dimension, there are three types of gestures describing fingers, namely atomic gestures, compound gestures, and parallel gestures [17]. Atomic gestures were performed with one finger, compound gestures were performed with multi-fingers of one hand, and parallel gestures were performed with two hands [17]. In this study, we added the palm and fist because some participants used the palm or the fist to perform some gestures, and no fingers were used (Table 1).

4.2 User-defined touch gestures on touchscreens

We firstly developed a user-defined gesture set according to [13]. The largest groups of identical gestures for each referent were assigned to represent the referent [13]. Then, we considered context and physical properties in user-defined gestures.

4.2.1 Agreement rate

We analyzed the recorded video of participants' gestures from the kinetic aspect. Sequences of kinetic gestures were mainly used to describe the interaction between the user and a designed product [30]. In this study, we observed how users would interact with the touchscreen when performing social touch gestures. Some examples of the kinetic gesture analysis are in Table 2.

We chose six aspects to describe a collected gesture—namely trajectory and dynamics [31], trajectory and dynamics descriptions [31], contact location of fingers, palm direction, cardinality dimension, and specific description about cardinality and trajectory (Table 2).

We adapted the trajectory and dynamics from [31] for kinetic gesture coding. From the aspect of trajectory and dynamics, a straight gesture is from a resting or an active position directly, with a straight trajectory, to the final position [31]. A repetitive gesture has repetitions that result in a metrical or rhythmical movement [31].

The two participants' gestures could be regarded as identical gestures when the six aspects (Table 2) of two participants' gestures of one social touch were the same. Identical gestures were used for calculating the agreement rate (AR) [24].

We generated a user-defined gesture set for mediated social touch (Fig. 4). Identical gestures of one social touch were grouped. The group with the largest size was then chosen to represent the user-defined gesture set [13].

To evaluate the degree of consensus among our participants, we adopted the process of calculating an agreement rate [24] for each referent. Vatavu and Wobbrock [24] propossed a mathematical calculation for the agreement rate [24], where:)

$$AR(r) = \frac{|P|}{|P|-1} \sum_{P_i \subseteq P} \left(\frac{|P_i|}{|P|} \right)^2 - \frac{1}{|P|-1} \tag{1}$$

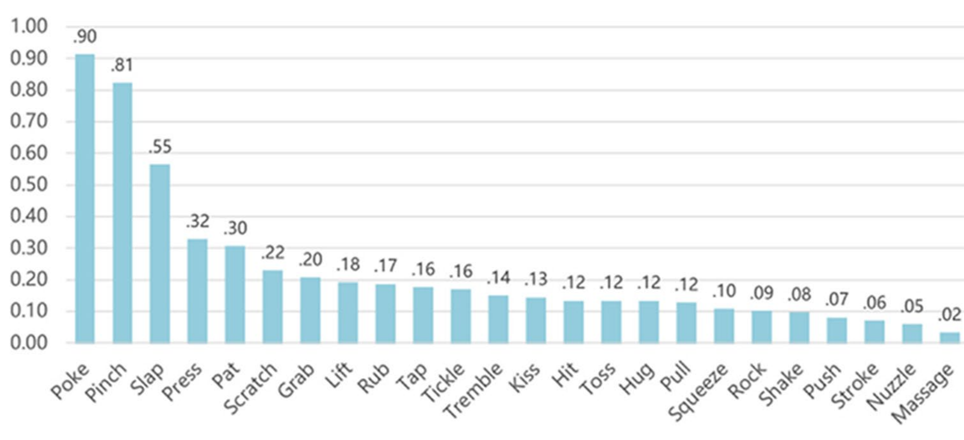

Fig. 3 Agreement rate

Table 2 Some examples of kinetic gesture analysis

Social touch	Participant	Trajectory and dynamics [31]	Trajectory and dynamics description [31]	Contact location with fingers	Palm direction	Cardinality dimension [17]	Specific description about cardinality and trajectory
Poke	P2	Straight	Starts from the air, stop on the touchscreen	Fingertips	Palm down	Atomic gestures: Index finger, right hand	One finger on one hand points one time
Tap	P3	Straight	Starts from the air, stop on the touchscreen	Knuckle	Palm up	Atomic gestures: Index finger, right hand	One finger knuckle on one hand points one time with the palm up
Scratch	P4	Straight	Move on the touchscreen	Fingernails	Palm down	Compound gestures: Index, middle, and ring finger, right hand	Three fingernails on one hand move on the touchscreen
Hit	P1	Straight	Starts from the air, stop on the touchscreen	Knuckle	Palm down	Fist, right hand	One fist hits one time
Squeeze	P3	Straight	Move on the touchscreen	Fingertips	Palm down	Parallel gestures: Thumbs, both hands	Two thumbs on two hands are approaching
Shake	P6	Repetitive	Move on the touchscreen repetitively	Fingertips	Palm down	Compound gestures: Index and middle finger, right hand	Two fingers on one hand move side to side together
Massage	P6	Kneading	Knead on the touchscreen repetitively	Fingertips	Palm down	Atomic gestures: Thumb, right hand	One thumb kneads
Tickle	P13	Straight	Starts from the air, stop on the touchscreen	Fingertips	Palm down	Compound gestures: Index and middle finger, right hand	Two fingers move a little from up to down two times

In Eq. 1, r is the referent, $|P|$ is the proposals collected for a given referent r. P_i represents subsets of participants from group P that are in agreement over r, $|P_i|$ donates the cardinality of subset P_i [17, 31, 32].

We applied AGATE tool (Agreement Analysis Toolkit) to compute agreement rates and p values [24] Fig. 3. illustrates the agreement rates. A mean agreement rate was 0.215. There was a significant effect of referent type on agreement rates [24] ($V_{rd(23,N=480)}$ = 1312.305, $p = 0.001$).

There were six referents whose agreement rate was less than 0.1, namely "Massage" (AR = 0.02), "Nuzzle" (AR = 0.05), "Stroke" (AR = 0.06), "Push" (AR = 0.07), "Shake" (AR = 0.08), and "Rock" (AR = 0.09). There were significant effects of referent type on agreement rate for these six referents ($V_{rd(5,N=120)}$ = 38.020, $p = 0.001$).

These referents had low agreement rates because most of these collected gestures belonged to metaphorical gestures (except for "Stroke"). Wobbrock et al. [13] have indicated that complex gestures are more likely to result in metaphorical gestures. It was normal that complex gestures had low agreement rates since each participant had their own understanding of a metaphor.

For "Stroke," most collected gestures were physical gestures, but "Stroke" still had a low agreement rate. The reason was that the "Stroke" between humans demanded no directions or exact fingers. However, participants moved different fingers in different directions on touchscreens, which resulted in a low agreement rate.

The agreement rate of "Massage" was the only one that was not significantly greater than zero ($V_{rd(1,N=20)}$ = 4.000, $p = 0.050$). So there was almost no consensus on a gesture for "Massage." The reason was that users had their own massage habits and massage techniques.

Referents with a higher agreement rate (AR > mean 0.215) included "Poke" (AR = 0.90), "Pinch" (AR = 0.81), "Slap" (AR = 0.55), "Press" (AR = 0.32), "Pat" (AR = 0.30), and "Scratch" (AR = 0.22). There were significant effects of referent type on agreement rate for these six referents ($V_{rd(5,N=120)}$ = 295.283, $p = 0.001$).

These referents with a higher agreement rate belonged to physical gestures. Wobbrock et al. [13] have indicated that simple gestures are more likely to result in physical gestures. It was normal that simple gestures had higher agreement rates.

4.2.2 Considering physical properties and context in user-defined touch gestures

In Fig. 4, there was no mapping relation between some social touch and a touch gesture. Wobbrock et al. [13] mentioned

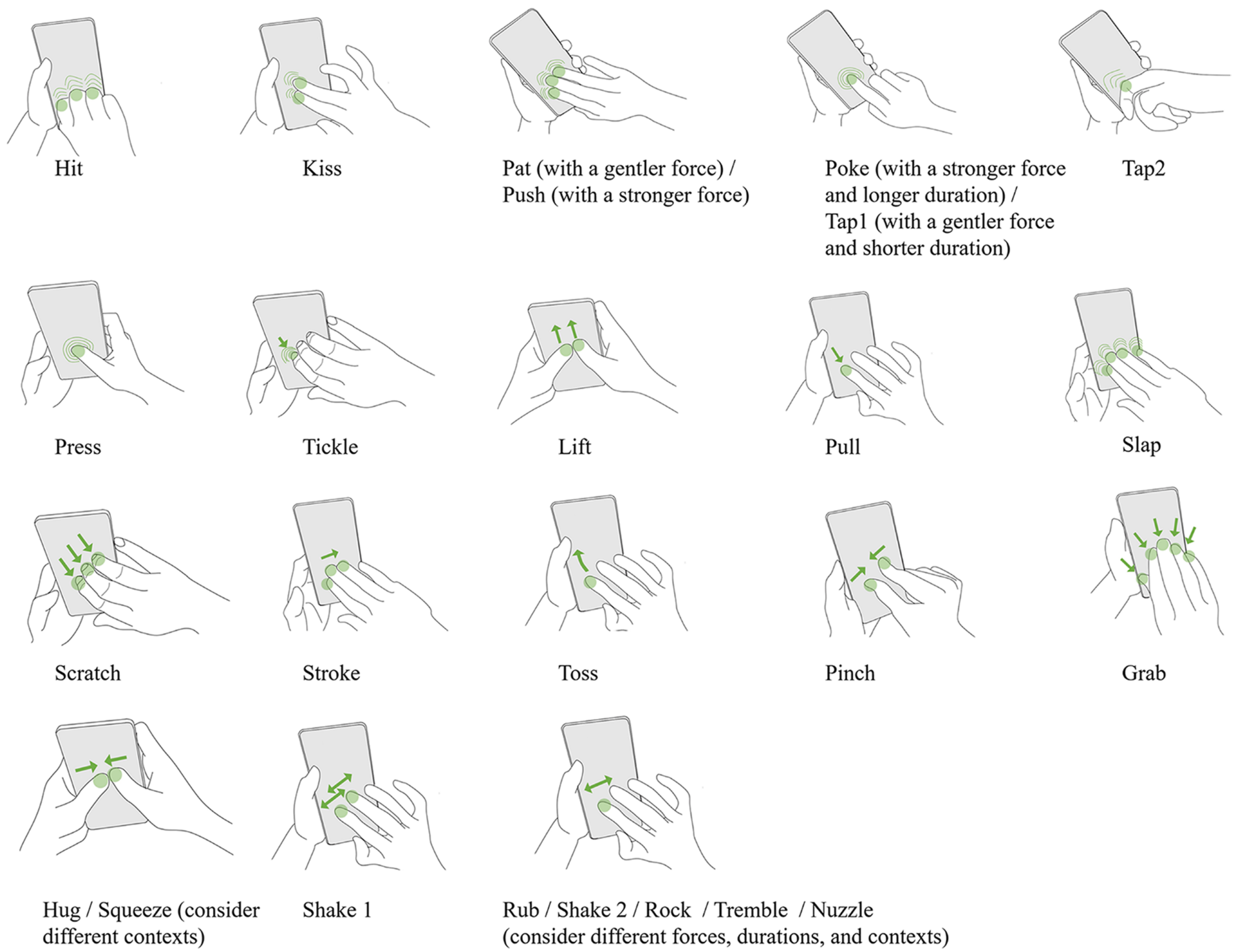

Fig. 4 User-defined gestures for mediated social touch on the touchscreen

where the same gesture was used to perform different commands, and a conflict occurred because one gesture cannot result in different outcomes. To resolve this, the referent with the largest group won the gesture [13].

However, we think there is a possibility to accept that one touch gesture could represent different meanings in mediated social touch.

1. *From the aspect of the definition, some social touch gestures indeed have similar kinetic features.* Definitions of those conflict social touch gestures from the Touch Dictionary [11] are in Table 3. For example, "Rub," "Tremble," "Shake," "Nuzzle", and "Rock" have the same user-defined gesture (Fig. 4). The definitions of these social touch gestures include descriptions like "back and forth" ("Rub" and "Rock"), "move side to side" ("Shake"), "shake against" ("Tremble"), "rub against" ("Nuzzle"). These descriptions belong to similar kinetic features. For "Poke" and "Tap," "Poke" means jab or prod with one finger, "Tap" means strike with one finger. The movements of these social touch gestures are similar, just with different forces and different rhythms. It is acceptable that the obtained user-defined gestures are the same since the movements in the gesture definition are similar. Different forces and rhythms could help to differentiate.
2. *From the aspect of context, mediated social touch is not like commands for mobile devices.* It highly depends on context. Some verbal and non-verbal expressions accompany a touching act, and whom we touch, when, and in what manner are regulated through social and personal norms [33]. It is important to take contextual factors into account [33]. As touch communicates emotion [11], it has been proved that a single-touch gesture can be used to communicate various emotions [27, 28]. For example, Yohanan and MacLean [11] showed the mean likelihood of touch gestures that would be used to communicate given emotions. For "Rub," the users'

Table 3 The definition of conflict user-defined gestures and recorded average maximum pressure and duration

Social touch	Gesture definition from [12]	Average pressure *	Average duration (s)
Pat	Gently and quickly touch the recipient with the flat of your hand	404	0.10
Push	Exert force on the recipient with your hand in order to move it away from yourself	898	0.60
Poke	Jab or prod the recipient with your finger	647	0.30
Tap	Strike the recipient with a quick light blow or blows using one or more fingers	446	0.08
Hug	Squeeze the recipient tightly in your arms. Hold the recipient closely or tightly around or against part of your body	827	1.00
Squeeze	Firmly press the recipient between your fingers or both hands	818	0.80
Rub	Move your hand repeatedly back and forth on the fur of the recipient with firm pressure	353**–605***	0.25****
Tremble	Shake against the recipient with a slight rapid motion	275**–508***	0.12****
Rock	Move the recipient gently back and forth or from side to side	362**–418***	0.20****
Shake	Move the recipient up and down or side to side with rapid, forceful, jerky movements	365**–627***	0.12****
Nuzzle	Gently rub or push against the recipient with your nose or mouth	191**–407***	0.20****

*We used Arduino to collect pressure, the pressure was a relative value, and the pressure range was from 0 to 1023.

Recorded pressure of repetitive gestures (explained in 4.3.1) fluctuated in a wavy pattern. The average pressure of the troughs** and the crests*** were applied here.

****The average duartion of repetitive gestures in this table was the duration between two adjacent troughs.

rates of "Depressed" and "Sleepy" were the same (both were 3.03 points). What the user exactly wants to communicate depends highly on a specific context. It is thus possible that one touch gesture could represent different social touch. If we consider different contexts, we could understand the different meanings of one touch gesture [17].

To differentiate gestures with the same movements, we could take the following aspects into account:

1. *Taking physical properties such as pressure and duration into consideration*. Villarreal-Narvaez et al. [34] indicate a secondary sense could serve for eliciting new ranges of symbols. The recorded pressure values of conflict gestures like "Poke" and "Tap" were different (Table 3). For the definition, "Poke" means "jab with the finger," which refers to a sudden strong movement, while "Tap" means "a light blow" [11] (Table 3). So, pressure is a significant factor to differentiate touch gestures on touchscreens. Duration is also helpful. The recorded durations were different for conflict gestures like "Shake" and "Rock" (Table 3). For the definition, "Shake" means rapid and forceful movements, while "Rock" means gentle movements [11] (Table 3). Most mobile devices have built-in sensors to compute pressure and contact duration [35]. Built-in sensors in mobile devices could help to differentiate these gestures [17].
2. *Taking context into consideration*. Tu et al. [17] indicate although assigning one gesture to multi-commands would cause a conflict, there should be no problem if the context is considered. For example, the touch gestures of "Hug" and "Squeeze" were the same (Fig. 4). There was no significant difference in recorded durations and pressures (Table 3), but different contexts could help to differentiate social touch with the same user-defined gesture. For example, in the context of comforting others, people may "Hug" rather than "Squeeze."
3. *Taking other modalities into account when developing applications*. Mediated social touch could present interpersonal touch over a distance through haptic or tactile displays [33]. Villarreal-Narvaez et al. [34] mentioned among primary human senses, vision and audition are covered much more than tactition, probably because our human brain filters signals so that the visual, auditory, and tactile channels respectively occupy 80%, 10%, and 5% of the total bandwidth. The haptic or tactile stimuli could be a compensation for visual and audio information. So other channels could help to differentiate mediated social touch when the touch gestures come the same.

4.3 Movement forms and physical properties

We provided movement forms to describe trajectory features for gesture interaction. The physical properties mainly refer to pressure and duration in this study.

4.3.1 Movement forms

Movement forms indicate the trajectory and dynamics of hands/fingers movement [31]. It also describes the spatial relations between the hands/fingers and the touchscreen. The movement forms have the following aspects:

1. *The classifications based on the movement forms consider gestures with general characteristics*. The general taxonomy of gesture is based on all collected gestures [13, 16, 17]. However, not all collected gestures for one social touch have general characteristics. We need to screen all collected gestures at first to exclude those without general characteristics. For example, the definition of "Stroke" is moving the hand over with gentle pressure over the subject [11]. We collected 20 gestures of "Stroke," 19 out of 20 participants moved their fingers on the touchscreen, and only one participant pointed to the touchscreen one time. We excluded this gesture for further analysis.
2. *The movement form of social touch does not consider the exact fingers*. The user-defined gesture comes from a group of identical gestures [13]. The specific fingers are the same for identical gestures. However, social touch is not like function commands. People have a preference when touching someone. There is no need to demand specific fingers. For example, "Scratch" means rub the subject with your fingernails [11]. The definition mentions fingernails, not the exact fingers. The recorded videos also showed that nine participants moved fingernails of the index, middle, and ring fingers from up to down, five participants moved fingernails of the index finger from up to down, and three participants moved fingernails of the index and middle fingers from up to down on the touchscreen. Although the used fingers were not the same for all participants, the meaning participants wanted to express was the same.
3. *The movement form of social touch considers spatial relations between the hands/fingers and the touchscreen*. There were aspects of hand poses, paths, and fingers in the original form proposed in [13]. It described if the hand pose was static or dynamic and if hands moved or not moved. It did not describe how the hands moved or what the specific path was. In this study, we regarded the touchscreen as the other person. Thus, it is important to consider spatial relations between the hands/fingers and the touchscreen.

We classified touch gestures based on movement forms. We considered movement forms and ignored the specific use of fingers when classifying the same gestures. For example, some participants "Pat" on the touchscreen with two fingers, while some used three or four fingers. These gestures were different when defining a touch gesture, but these were classified as the same type based on the movement forms.

Four categories of social touch (Fig. 2b and Table 4) on the touchscreen based on movement forms were extracted—including straight gestures on the touchscreen (SOT), straight gestures from the air (SFA), repetitive gestures (RPT) on the touchscreen, and kneading gestures on the touchscreen (KOT). These four categories were adapted from [31]:

- SOT gestures move from a resting position on the touchscreen with a straight trajectory to another position (so-called phasic gestures in [31]). Examples of SOT

Table 4 Gesture classification based on movement forms

Dimension	Types	Description	Social touch
Movement forms	SFA	SFA gestures move from the air with a straight trajectory to one point on the touchscreen, with a quick contact with the touchscreen	Hit, Kiss, Pat, Poke, Press, Slap, Tap, Tickle
	SOT	SOT gestures move from a resting position on the touchscreen with a straight trajectory to another position	Scratch, Stroke, Lift, Pull, Push, Toss, Grab, Hug, Pinch, Squeeze
	RPT	RPT gestures move on the same trajectory repetitively	Rock, Nuzzle, Rub, Shake, Tremble
	KOT	KOT gestures knead on the touchscreen repetitively	Massage
Duration	Short	It took less than 0.3 s	Hit, Kiss, Pat, Poke, Slap, Tap, Tickle
	Medium	It took less than 0.6 s, more than 0.3 s	Press, Toss, Grab, Scratch, Stroke
	Long	It took more than 0.6 s	Lift, Pull, Push, Hug, Pinch, Squeeze, Rock, Nuzzle, Rub, Shake, Tremble, and Massage
Pressure*	Gentle	The recorded pressures were less than 500*	Pat, Stroke, Rock, Tap, Tickle, Scratch, Nuzzle
	Medium	The medium pressure was between 500* and 700*	Toss, Poke, Rub, Shake, Tremble
	Strong	The recorded pressures were more than 700*	Squeeze, Slap, Hit, Hug, Pinch, Kiss, Press, Grab, Lift, Pull, Push, Massage

*We used Arduino to collect pressure, the pressure was a relative value, and the pressure range was from 0 to 1023.

gestures are "Scratch," "Stroke," "Lift," "Pull," "Push," "Toss," "Grab," "Hug," "Pinch," and "Squeeze."

- SFA gestures move from the air with a straight trajectory to one point on the touchscreen, with a quick contact with the touchscreen. Examples are "Hit," "Kiss," "Pat," "Poke," "Press," "Slap," "Tap," and "Tickle."
- RPT gestures on the touchscreen have repetitive movements on the touchscreen. As shown in [31], repetitive gestures involve repetitive movements—the repetition results in metrical or rhythmical movements [31]. For example, in "Rock," "Nuzzle," "Rub," "Shake," and "Tremble," participants moved their fingers up–down–up–down on the touchscreen.
- KOT gestures stay on the touchscreen with a kneading movement repetitively. These gestures refer to social touch expressing changing force primarily, such as "Massage."

4.3.2 Duration

The duration refers to the contact time that fingers touch the touchscreen. We did not consider the time when the hands/fingers were in the air.

To explore the characteristics of social touch on the largest consensus, we considered the mean duartion of each gesture in the same movement forms. We excluded gestures that had no general characteristics with others because these gestures may be extreme values, and their characters may not contribute to the description of the specific social touch.

Short-duartion gestures included single taps on the touchscreen [14], which belong to the SFA group. They took less than 0.3 s in the SFA group based on our recorded duration. Gestures in the SFA group ("Hit," "Kiss," "Pat," "Poke," "Slap," "Tap," "Tickle") were all categorized in the short-duration group.

Medium-duartion gestures included "Press," "Scratch," "Stroke," "Toss," and "Grab." They belonged to the SFA group and the SOT group. "Toss" and "Grab" were two gestures that involved gesture movements in the air, and they took less than 0.6 s, more than 0.3 s. The rest gestures in the SOT group took a longer duration than the SFA group. It took more than 0.6 s in the SOT group.

Gestures categorized as long in duration included the rest of the gestures in the SOT group ("Lift," "Pull," "Push," "Hug," "Pinch," and "Squeeze"), RPT gestures ("Rock," "Nuzzle," "Rub," "Shake," and "Tremble"), and KOT gestures ("Massage") took longer duartion. They were all categorized in the long-duartion group for more than 0.6 s (Table 4).

4.3.3 Pressure

We considered the mean maximum pressure of each social touch in the same movement forms. Although the pressure was changing on the touchscreen, the maximum pressure could be the main characteristics when describing a social touch [36]. We used the relative pressure recorded by Arduino, ranging from 0 to 1023.

Gentle pressure touch included "Pat," "Nuzzle," "Stroke," "Rock," "Tap," and "Tickle." The definitions of these social touch gestures included words like "gentle" or "light" [11]. The recorded pressure values were less than 500. According to recorded pressure, other gentle pressure touch included "Scratch."

Strong pressure touch included "Squeeze," "Slap," "Hit," "Hug," and "Pinch" because they were described using words like "firmly," "sharply," "tightly," or "forcible" [11]. The recorded pressure values were more than 700. According to recorded pressure, other strong pressure touch gestures included "Kiss," "Press," "Grab," "Lift," "Pull," "Push," and "Massage."

Medium pressure touch included "Toss," "Poke," "Rub," "Shake," and "Tremble." The medium pressure was between 500 and 700 (Table 4).

4.4 Subjective ratings

4.4.1 Ease of performing and usage frequency

We conducted the Friedman test and the Spearman correlation analysis as [32] did.

1. *Ease of performing*. A Friedman test indicated a significant effect of referent type on ease of performing (χ^2 (20) = 154.589, $p < 0.001$). The top eight (mean ≥ 5.5) referents were "Pat," "Press," "Poke," "Slap," "Scratch," "Tap," "Stroke," and "Tickle." These social touch gestures had higher scores because the user-defined gestures on the touchscreen were the same as the social touch in real human–human interaction. Social touch gestures with lower ratings (mean ≤ 4.5) were "Hug," "Pull," "Tremble," "Grab," "Lift," "Kiss," "Nuzzle," "Rock," "Toss," and "Squeeze." The user-defined gestures for these social touch gestures on the touchscreen were a metaphor of the social touch in real human–human interaction. We also conducted the Friedman test and the Spearman correlation analysis as [32] did. We found a positive correlation between agreement rate and ease of performing ($r_{(N=24)} = 0.430$, $p = 0.036$ (two-tailed)). This result indicated that gestures which were easier to perform had a larger consensus (Fig. 5).
2. *Usage frequency*. A Friedman test indicated a significant effect of referent type on usage frequency (χ^2

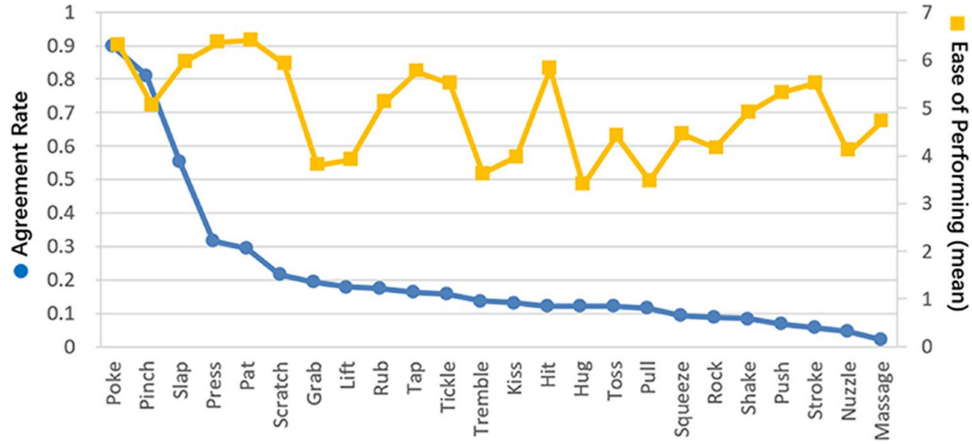

Fig. 5 Correlation between agreement rate and ease of performing, Spearman's $r_{(N=24)} = 0.430$, $p = 0.036$ (two-tailed)

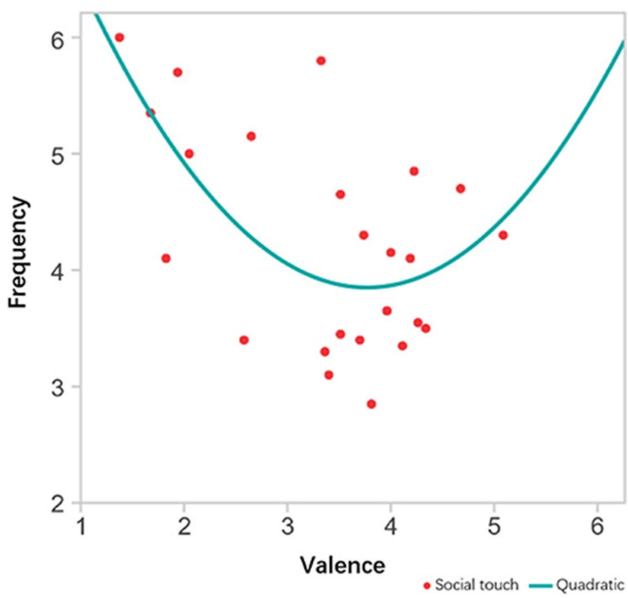

Fig. 6 Curves estimation regression analysis between frequency and valence, $r^2 = 0.381$, $p=0.007$

(20) = 122.655, $p < 0.001$). Users were more likely to use social touch like "Kiss," "Poke," "Stroke," "Hug," "Pat," and "Tickle" (mean ≥ 5). Users used less social touch like "Pull," "Rub," "Lift," "Squeeze," "Massage," "Tremble," "Rock," and "Scratch" (mean ≤ 3.5). A curve estimation was conducted in SPSS. For valence, curve estimation regression analysis showed the quadratic equation had the highest correlation between frequency and valence ($r^2 = 0.381$, $p = 0.007$) (Fig. 6). Users preferred to use high valence and low valence social touch more often than the social touch with a median valence. Users were more likely to express positive or negative emotions in online communication than neutral emotions.

4.4.2 Relationship among ease of performing, usage frequency, and physical properties

To find out if there were some correlations among ease of performing, usage frequency, and physical properties, we conducted the Spearman correlation analysis (Fig. 7).

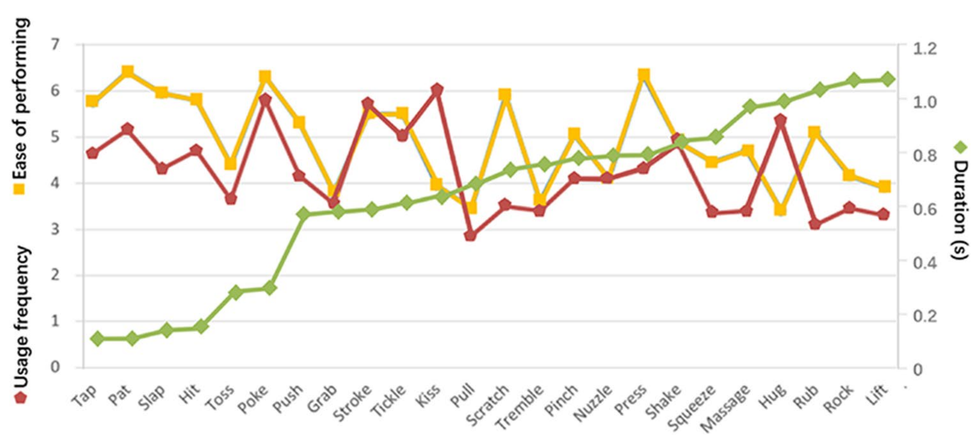

Fig. 7 Correlation between duration and ease of performing, Spearman's $r_{(N=24)} = -0.494$, $p=0.014$ (two-tailed), and between duration and usage frequency, Spearman's $r_{(N=24)} = -0.483$, $p=0.017$ (two-tailed)

1. *Ease of performing and usage frequency*. With 24 social touch gestures chosen from Touch Dictionary [11], there was a positive correlation between the ease of performing and the usage frequency ($r_{(N=24)} = +0.410$, $p = 0.046$ (two-tailed)). People were inclined to use easier social touch more often. As [14] showed, the participants preferred simple user-defined gestures and believed that simple gestures were easier to perform and remember.
2. *Duration and ease of performing*. A negative correlation was observed between the duration and ease of performing ($r_{(N=24)} = -0.494$, $p = 0.014$ (two-tailed)). Social touch gestures with shorter duration were easier to perform because those short-duartion gestures were mainly simple gestures, like "tap" and "poke," which were examples of simple gestures [14].
3. *Duration and usage frequency*. A negative correlation was observed between the duration and usage frequency ($r_{(\mathrm{N}=24)} = -0.483$, $p = 0.017$ (two-tailed)). As mentioned above, short-duartion gestures were mainly simple gestures [14], like "tap" and "poke." Simple gestures were similar to the touch gestures used often for touchscreens.
4. Pressure, duration, ease of performing, and usage frequency. No significant correlations were observed between pressure and duration ($p = 0.105$), pressure and ease of performing ($p = 0.231$), pressure and usage frequency ($p = 0.271$).

4.4.3 Movement forms, ease of frequency, and usage frequency

We explored if the movement forms of social touch affected ease of performing and usage frequency. The values of the Likert scale from participants whose touch gestures were in the same movement forms for each social touch were averaged and combined into one data set [32]. We excluded "Massage" (KOT group) because there was only one social touch in the KOT group.

1. *Movement forms and ease of performing*. There were significant differences in the ease of performing in different movement forms ($F(2,22) = 6.647$, $p = 0.006$). Post hoc analysis (LSD) showed that significant differences were observed between the SFA group and the SOT group ($p = 0.004$) and between the SFA group and the RPT group ($p = 0.007$). No significant differences were observed between the SOT group and the RPT group ($p = 0.746$). The result showed that the SFA gestures were easier to perform because they were simple gestures and had a shorter duration and gentler pressure. These social touch gestures were easier to perform. Social touch gestures in POT and RPT groups were mostly metaphorical, and they were not easy to perform.
2. *Movement forms and usage frequency*. There were significant differences in the usage frequency in different movement forms ($F(2,22) = 5.137$, $p = 0.016$). Post hoc analysis (LSD) showed that significant differences were observed between the SFA group and the SOT group ($p = 0.011$) and between the SFA group and the RPT group ($p = 0.014$). No significant differences were observed between the POT gestures and the RPT gestures ($p = 0.697$). The result showed that the SFA gestures were used more often. This result was connected with the above results. Social touch in the SFA group (Table 4) were simple gestures. Simple gestures were used more often for touchscreen interaction (mentioned in 4.2.2).

5 Discussion and limitations

In this study, we conducted an elicitation study. We obtained user-defined gestures for mediated social touch on the touchscreen of smartphones considering physical properties and context. The user-defined gestures conform to the context of holding a smartphone in hand (e.g., text or video calling). We also collected pressure and duration of user-defined gestures. Based on these results, we have some discussions.

In this section, we discuss the limitations of the study and the implications for the design and application of our results in the field of mediated social touch.

5.1 Implications for user-defined gestures considering physical properties and context

Physical properties could expand the space for gesture differences. Wobbrock et al. [13] indicated that the same gesture might cause conflicts to invoke commands, so the referent with the largest group won the gesture. But sometimes, it was not possible to discard any referents since both referents would be used frequently. In this case, physical properties could help to differentiate social touch. For example, "Rock" and "Shake" could use the same user-defined gesture (Fig. 4) with the pressures differed. Adding pressure to the gesture could help differentiate them.

Context could help to differentiate social touch when the touch gestures were the same and the pressures were similar. For example, "Hug" and "Squeeze" had the same gesture (Fig. 4) and similar pressure (Table 3). Suppose one couple expressed love for each other with this gesture, so they may want to "Hug" with each other rather than "Squeeze" since "Squeeze" sometimes could represent an emotion of anger or fear [28].

Based on the above, designers or researchers could confirm the context before the design. Make sure if there are conflicts in the mediated social touch, which may confuse the users. Put these considerations into the design practice. And take advantage of the unique physical properties and contexts in design for the differentiation. For example, if we design vibrations to reflect mediated social touch. "Shake" should have a strong intensity than "Rock" since "Shake" has a higher collected pressure than "Rock."

5.2 Implications for gesture recognition of mediated social touch

Jung et al. [36] provided Corpus of Social Touch and demonstrated that it was possible to recognize mediated social touch gestures. The primary data collected for gesture recognition in [36] were pressure (mean/maximum pressure variability/per column/per row, and peak count), duration, and trajectory (contact area and displacement). We collected pressure, duration, and trajectory data. If we considered processing collected data as [36], it was possible to reach gesture recognition for mediated social touch on touchscreens in the future.

Based on the above, designers or researchers could first confirm if the transmission ways of mediated social touch are for real-time transmission or not. If the real-time transmission is needed, gesture recognition of mediated social touch may be needed.

5.3 Implications of movement forms applications

Movement forms may help us simplify the mediated social touch design on a large scale. Social touch in the same movement forms has similar physical properties. We could design mediated social touch on a macro-aspect first. For example, if we design mediated social touch with haptic stimuli, the vibration signal could all be a short pulse in the SFA group because the contact time with the touchscreen is very short. While in the SOT group, the vibration signal could be long because the contact time in this group was mainly long. Then, in each group, pressure could be the factor to differentiate some social touch. Different amplitudes in vibration signals could control different pressures of the social touch.

Based on the above, designers or researchers could confirm the type of mediated social touch before design, especially when a lot of mediated social touch needs to be considered. It is efficient to apply the common characteristics of mediated social touch to simplify the design process.

5.4 Implications from subjective ratings

The subjective ratings (ease of performing, usage frequency, arousal, and valence) could provide a design basis for mediated social touch design.

The main correlation results were (1) social touch with short duration was often easier to perform, (2) social touch with easier gestures was usually used more often, and (3) when sharing emotional expressions in online communication, happy and sad emotions were used more often, while neutral emotions were less used.

In design, we could design more forms for frequently used social touch and emotions. Designing more forms for frequently used features is commonly used in the application of current social networking. For example, smileys are used very frequently for emojis, so there are many types of emojis express smileys, such as grinning face, beaming face with smiling eyes, and rolling on the floor laughing [37]. If we design through haptic stimuli, we could provide different vibration types for one social touch, as [38] showed a different combination of frequency, amplitude, duration, and envelope could present a similar emotional expression.

In the design of gestures that are not easy to perform, we may apply multimodal modalities to display mediated social touch (e.g., a combination of visual, audio, and tactile information). Multimodal modalities may provide an opportunity to simplify the gestures that users should perform physically. For example, we could design stickers or gifs to show the gestures. Users just need to press the touchscreen to trigger the visual gestures, so they do not need to perform it physically.

Based on the above, designers or researchers could confirm the design demands of the application first. Check if more types of stimuli of mediated social touch are needed for users. And make sure what kind of stimuli and modalities that users prefer in different contexts to make the design more efficient and meet users' demands.

5.5 Implications for design fuzzy mediated social touch

The emotion could be another design space for mediated social touch. It has been demonstrated that touch communicates emotion [12, 27, 39]. Sometimes, there is no need to know the specific touch when expressing emotion, as many social touch gestures could express a similar emotion. We could design vibrations expressing high arousal or low arousal with similar social touch if we design with haptic stimuli. This aspect could help to simplify the design.

Based on above, designers or researchers could confirm if their target users need the precise mediated social touch or fuzzy emotion expressions. These two demands may lead to different design methods.

5.6 Limitations

We only considered the touchscreen of a smartphone and ignored the spatial dimension of the smartphone (e.g., tilting, panning, and shaking the smartphone were not considered). We did not examine which conditions users preferred.

Especially for repetitive gestures like "Shake," "Tremble," and "Rock," some users asked if shaking the smartphone was possible during the experiment. This means considering spatial dimension may be needed. In the future, we could consider the spatial dimension and compare the differences between two conditions (i.e., considering spatial dimension vs. ignoring spatial dimension). It could provide a more comprehensive understanding of delivering mediated social touch via smartphones.

We only considered the smartphone in this study. We did not consider other mobile devices with larger screens (e.g., tablets). Users may have different ways to perform mediated social touch on different mobile devices as users may have different holding postures for different mobile devices. Tu et al. [17] have already indicated that different holding postures could lead to different gestures for one referent.

There are some limitations for the age group of participants. We mainly recruited participants from the campus. We did not consider the age group under 23 or over 35. Teenagers or older people may have a different insight of performing mediated social touch on touchscreens. But participants we recruited were also active users in social media, and they could still cover a specific spectrum.

6 Conclusions and future work

We conducted an elicitation study to explore mediated social touch on the touchscreen of smartphones. Our main contributions are as follows:

- Quantitative and qualitative characterization of mediated social touch.
- A user-defined social touch gesture set on touchscreens considering physical properties and context.
- Gesture classifications based on the movement forms.
- Implications for mediated social touch technology and its application.

In the future, we will consider how to perform mediated social touch on different mobile devices and try to reach a more comprehensive guideline for mediated social touch design for mobile devices. On the other hand, we will try to apply the user-defined gestures and related data of physical properties (pressure and duration) to design mediated social touch with vibrotactile stimuli. We will establish a tangible interaction between humans via mediated social touch with vibrotactile stimuli on mobile devices.

Declarations

Conflict of interest The authors declare no competing interests.

References

1. Rantala J, Salminen K, Raisamo R, Surakka V (2013) Touch gestures in communicating emotional intention via vibrotactile stimulation. Int J Hum Comput Stud 71:679–690. https://doi.org/10.1016/j.ijhcs.2013.02.004
2. Haans A, IJsselsteijn W, (2006) Mediated social touch: a review of current research and future directions. Virtual Real 9:149–159. https://doi.org/10.1007/s10055-005-0014-2
3. Gordon ML, Zhai S (2019) Touchscreen haptic augmentation effects on tapping, drag and drop, and path following. In: Proceedings of the 2019 CHI Conference on Human Factors in Computing Systems (CHI'19). ACM, Glasgow, Scotland, UK, pp 1–12. https://doi.org/10.1145/3290605.3300603
4. Liu S, Cheng H, Chang C, Lin P (2018) A study of perception using mobile device for multi-haptic feedback. In: International Conference on Human Interface and the Management of Information (HIMI 2018). Springer, Las Vegas, NV, USA, pp 218–226 https://doi.org/10.1007/978-3-319-92043-6_19
5. Park YW, Baek KM, Nam TJ (2013) The roles of touch during phone conversations: long-distance couples' use of POKE in their homes. In: Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI'13). ACM, Paris, France. pp 1679–1688. https://doi.org/10.1145/2470654.2466222
6. Park Y, Bae SH, Nam TJ (2012) How do couples use CheekTouch over phone calls? In: Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI'12). ACM, Austin, TX, USA. pp 763–766. https://doi.org/10.1145/2207676.2207786
7. Park YW, Bae SH, Nam TJ (2016) Design for sharing emotional touches during phone calls. Arch Des Res 29:95–106. https://doi.org/10.15187/adr.2016.05.29.2.95
8. Hoggan E, Stewart C, Haverinen L, et al. (2012) Pressages: augmenting phone calls with non-verbal messages. In: Proceedings of the 25th Annual ACM Symposium on User Interface Software and Technology (UIST'12). ACM, Cambridge, MA, USA. pp 555–562. https://doi.org/10.1145/2380116.2380185
9. Hemmert F, Gollner U, Löwe M, et al. (2011) Intimate mobiles: grasping, kissing and whispering as a means of telecommunication in mobile phones. In: Proceedings of the 13th International Conference on Human Computer Interaction with Mobile Devices and Services (MobileHCI'11). ACM, Stockholm, Swedem. pp 21–24. https://doi.org/10.1145/2037373.2037377
10. Furukawa M, Kajimoto H, Tachi S (2012) KUSUGURI: a shared tactile interface for bidirectional tickling. In: Proceedings of the 3rd Augmented Human International Conference (AH'12). ACM, Megève, France. pp 1–8. https://doi.org/10.1145/2160125.2160134
11. Yohanan S, MacLean KE (2012) Robot interaction: human intent and expectations in touching the haptic creature. Int J Soc Robot 4:163–180. https://doi.org/10.1007/s12369-011-0126-7
12. Chang A, O'Modhrain S, Jacob R, et al. (2002) ComTouch: design of a vibrotactile communication device. In: Proceedings of the 4th conference on Designing interactive systems: processes, practices, methods, and techniques (DIS'02). ACM, London, England, UK. pp 312–320. https://doi.org/10.1145/778712.778755
13. Wobbrock JO, Morris MR, Wilson AD (2009) User-defined gestures for surface computing. In: Proceedings of the SIGCHI conference on human factors in computing systems (CHI'09). ACM, Boston, MA, USA. pp 1083–1092. https://doi.org/10.1145/1518701.1518866
14. Shimon SA, Lutton C, Xu Z, et al. (2016) Exploring non-touchscreen gestures for smartwatches. In: Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI'16). ACM, San Jose, CA, USA, pp 3822–3833. https://doi.org/10.1145/2858036.2858385

15. Dim NK, Ren X (2014) Designing motion gesture interfaces in mobile phones for blind people. J Comput Sci Technol 29:812–824. https://doi.org/10.1007/s11390-014-1470-5
16. Ruiz J, Li Y, Lank E (2011) User-defined motion gestures for mobile interaction. In: Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI'11). ACM, Vancouver, BC, Canada, pp 197–206. https://doi.org/10.1145/1978942.1978971
17. Tu H, Huang Q, Zhao Y, Gao B (2020) Effects of holding postures on user-defined touch gestures for tablet interaction. Int J Hum Comput Stud 141:102451. https://doi.org/10.1016/j.ijhcs.2020.102451
18. Findlater L, Lee BQ, Wobbrock JO (2012) Beyond QWERTY: augmenting touch-screen keyboards with multi-touch gestures for non-alphanumeric input. In: Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI'12). ACM, Austin, TX, USA, pp 2679–2682. https://doi.org/10.1145/2207676.2208660
19. Kurdyukova E, Redlin M, André E (2012) Studying user-defined iPad gestures for interaction in multi-display environment. In: Proceedings of the 2012 ACM international conference on Intelligent User Interfaces (IUI'12). ACM, New York, NY, USA, pp 93–96. https://doi.org/10.1145/2166966.2166984
20. Shimon SSA, Morrison-Smith S, John N, et al. (2015) Exploring user-defined back-of-device gestures for mobile devices. In: Proceedings of the 17th International Conference on Human-Computer Interaction with Mobile Devices and Services (MobileHCI'15), New York, NY, USA, pp 227–232. https://doi.org/10.1145/2785830.2785890
21. Wu H, Yang L (2020) User-defined gestures for dual-screen mobile interaction. Int J Hum Comput Interact 36:978–992. https://doi.org/10.1080/10447318.2019.1706331
22. Liang HN, Williams C, Semegen M, et al. (2012) User-defined surface+motion gestures for 3D manipulation of objects at a distance through a mobile device. In: Proceedings of the 10th Asia pacific conference on Computer human interaction (APCHI'12). ACM, Matsue-city, Shimane, Japan, pp 299–308. https://doi.org/10.1145/2350046.2350098
23. Rust K, Malu M, Anthony L, Findlater LK (2014) Understanding child-defined gestures and children's mental models for touchscreen tabletop interaction. In: Proceedings of the 2014 conference on Interaction design and children (IDC'14). ACM, Aarhus, Denmark, pp 201–204. https://doi.org/10.1145/2593968.2610452
24. Vatavu RD, Wobbrock JO (2015) Formalizing agreement analysis for elicitation studies: new measures, significance test, and toolkit. In: Proceedings of the 33rd Annual ACM Conference on Human Factors in Computing Systems (CHI'15). ACM, New York, NY, USA, pp 1325–1334. https://doi.org/10.1145/2702123.2702223
25. Hurtienne J, Stößel C, Sturm C et al (2010) Physical gestures for abstract concepts: inclusive design with primary metaphors. Interact Comput 22:475–484. https://doi.org/10.1016/j.intcom.2010.08.009
26. Oulasvirta A, Reichel A, Li W, Vertanen K (2013) Improving two-thumb text entry on touchscreen devices. In: Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI'13). ACM, Paris, France, pp 2765–2774. https://doi.org/10.1145/2470654.2481383
27. Hertenstein MJ, Keltner D (2006) Touch communicates distinct Emotions. Emotion 6:528–533. https://doi.org/10.1037/1528-3542.6.3.528
28. Hertenstein MJ, Holmes R, McCullough M, Keltner D (2009) The communication of emotion via touch. Emotion 9:566–573. https://doi.org/10.1037/a0016108
29. Lang PJ, Bradley MM, Cuthbert BN (1997) International affective picture system (IAPS): technical manual and affective ratings. NIMH Cent Study Emot Atten 1:39–58. https://doi.org/10.1007/978-3-319-28099-8_42-1
30. Bekker MM, Olson JS, Olson GM (1995) Analysis of gestures in face to face design teams provides guidance for how to use groupware in design. In: Proceedings of the 1st conference on Designing interactive systems: processes, practices, methods, & techniques (DIS'95). ACM, Ann Arbor, MI, USA, pp 157–166. https://doi.org/10.1145/225434.225452
31. Lausberg H, Sloetjes H (2009) Coding gestural behavior with the NEUROGES-ELAN system. Behav Res 41:841–849. https://doi.org/10.3758/BRM.41.3.841
32. Zaiţi IA, Pentiuc ŞG, Vatavu RD (2015) On free-hand TV control: experimental results. Pers Ubiquitous Comput 19:821–838. https://doi.org/10.1007/s00779-015-0863-y
33. Askari SI, Haans A, Bos P, et al. (2020) Context matters: the effect of textual tone on the evaluation of mediated social touch. In: International Conference on Human Haptic Sensing and Touch Enabled Computer Applications (EuroHaptics'20). Springer, Leiden, Netherlands, pp 131–139. https://doi.org/10.1007/978-3-030-58147-3_15
34. Villarreal-Narvaez S, Vanderdonckt J, Vatavu RD, Wobbrock JO (2020) A systematic review of gesture elicitation studies: what can we learn from 216 studies? In: Proceedings of the 2020 ACM Designing Interactive Systems Conference (DIS'20). ACM, Eindhoven, Nertherland, pp 855–872. https://doi.org/10.1145/3357236.3395511
35. Patel VM, Chellappa R, Chandra D, Barbello B (2016) Continuous user authentication on mobile devices: recent progress and remaining challenges. IEEE Signal Process Mag 33:49–61. https://doi.org/10.1109/MSP.2016.2555335
36. Jung MM, Poppe R, Poel M, Heylen DKJ (2014) Touching the void - introducing CoST: Corpus of social touch. In: Proceedings of the 16th International Conference on Multimodal Interaction (ICMI'14). ACM, Istanbul, Turkey, pp 120–127. https://doi.org/10.1145/2663204.2663242
37. Emojis for smileys, people, families, hand gestures, clothing and accessories. https://emojipedia.org/people/
38. Yoo Y, Yoo T, Kong J, Choi S (2015) Emotional responses of tactile icons: effects of amplitude, frequency, duration, and envelope. In: 2015 IEEE World Haptics Conference (WHC'15). IEEE, Evanston, IL, USA, pp 235–240. https://doi.org/10.1109/WHC.2015.7177719
39. Réhman SU, Liu L (2008) iFeeling: vibrotactile rendering of human emotions on mobile phones. In: Workshop of Mobile Multmedia Processing (WMMP'08). Springer, Tampa, FL, USA, pp 1–20. https://doi.org/10.1007/978-3-642-12349-8_1