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Mediated Social Touch with Mobile Devices: A Review of Designs and Evaluations

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***Abstract*—Background:** Mediated social touch has been widely studied for remote affective communication in the field of human-computer interaction. **Goal**: We conducted this literature review to comprehensively understand the state of the art of the designs and evaluations of mediated social touch for mobile devices. **Method:** We selected 52 articles based on related keywords from four main digital libraries, i.e., ACM, IEEE, Springer, and Scopus. **Results**: We summarized from these articles how mediated social touch signal is designed, prototyped, and evaluated, and what the main research findings are. Based on the analysis, we identified opportunities for later work.

***Index Terms*—mediated social touch, mobile devices, haptic technology, emotion, affective communication.**

1 Introduction

Mediated social touch (MST) is a new form of remote affective communication [1]. New advanced haptic technologies and new applications make this field flourish. Jarzyna [2] indicated that the explosion of digital media in the recent two decades augments the fulfilment of real relationships with para socialization. Moreover, the COVID-19 quarantine in recent years restricted real socialization [2] and isolated people more [3]. Many researchers have done research to compensate for the lack of real touch in an isolated situation [4].

Advanced touch technologies in new actuators make MST possible. For example, linear resonance actuators (LRA) can help people feel the flexing of the remote partner's finger touch effects by controlling a linear sequential vibration pattern [5]. Piezoelectric actuators [6] can be embedded in a touchscreen to provide friction. Tpad can create the perception of force, shape, and texture on a fingertip [7]. Mullenbach et al. [6] demonstrated that affective communication through this variable-friction Tpad was possible.

The current mobile applications (e.g., text, voice calls, video calls, et al.), and remote collaborative tasks for remote users can all be enhanced with the compensation of real touch. Many researchers developed prototypes to transmit MST signals in remote communication. For example, Kissgener [8], [9], CheekTouch [10], [11], KUSUGURI [12], MobiLimb [13], POKE [14], SansTouch [15], and SqueezeBands [16] can create effects of kiss [8], [9], [10], [11], tickle [10], [11], [12], [14], stroke [13], pat [14], poke [14], handshakes [15], and squeeze [16] in daily interpersonal communication and collaborative tasks.

Many researchers have conducted literature reviews in the MST fields. For example, Eid and Osman [17], Huisman [18], and van Erp and Toet [19] reviewed affective haptics and haptic technologies for social touch in human-computer interaction. They summarized the applications for social touch (e.g., affective haptics in social interaction, healthcare, gaming and entertainment, human-robot interaction, etc.), and the effects of social touch (physical, emotional well-being attachment, bonding, behavior changing, etc.). Culbertson et al. [20] studied artificial touch, introduced different haptic interfaces, and discussed integration with virtual and augmented reality.

These reviews have provided a detailed overview of MST in human-computer interaction. We still found most of them discussed mobile devices, wearables, virtual agents, and other haptic devices together. However, the technologies and psychophysics theories could be different when the haptic stimuli work on different body parts.

In this paper, we focus on mobile devices since Rognon et al. [21] have found that mobile devices (e.g., cell phones and tablets) are popular devices that users use to communicate social touch. We want to explore which actuators, parameters, and prototypes researchers use to express and communicate MST signals with mobile devices and how they have evaluated their designs. We also want to derive guidelines for future work.

2 Method

2.1 Literature search

We mainly searched literature from the following databases: ACM digital library, IEEE Explore, SpringerLink, and Scopus because they provided important journal and conference papers in the intersection of social computing and touch technology [22].

We chose keywords for search from three aspects: technology, goal, and carrier (Table 1).

TABLE I
KEY WORDS FOR LITERATURE SEARCH

Categories	Detailed key words
Technology	Haptic, tactile, vibrotactile, vibration
Goal	Goal 1 (touch): MST, remote touch, social touch, touch gesture

	Goal 2 (communication): social communication, remote communication
	Goal 3 (emotion): affective communication, emotion
Carrier	Smartphone, touchscreen, mobile device, tablet, phone, mobile surface

For keywords in Goal, as touch communicates emotions [23] and haptic stimuli can be used for remote affective communication [17], we chose three goals: touch, communication, and emotion (Table 1).

The detailed Boolean search string is as follows:

("haptic" OR "vibrotactile" OR "tactile" OR "vibration") AND ("mediated social touch" OR "remote touch" OR "social touch" OR "touch gesture" OR "social communication" OR "remote communication" OR "emotion" OR "affective communication") AND ("smartphone" OR "touchscreen" OR "mobile device" OR "tablet" OR "phone" OR "mobile surface").

We followed the PRISMA flow chart [24]. We followed four steps to select articles (Figure 1).

In step 1, we used the above-mentioned Boolean search string in each database.

In step 2, as researchers started to study MST signals and gestures on mobile devices around 2008, so we limited the time from January 2008 to August 2022. We mainly included research articles (journal and conference papers). We excluded reviews, monographs, abstracts, posters, demonstrations, surveys, tutorials, notes, index, introductions, invited talks, keynotes, prefatory, books, reference work entries, reference work, protocols, and papers in a non-English language.

In step 3, we conducted title and abstract screening. We chose papers meeting our needs. This means the chosen paper was for at least one of our goals, using touch technology and mobile devices. We also added some papers from other resources.

In step 4, we conducted careful screening. We read the whole paper and made sure the article met our needs.

2.2 Article selection

During the careful screening phase, we found many researchers developed new prototypes for mobile communication. We needed to clarify the criteria for these prototypes. The inclusion criteria had the following considerations:

- The prototype should be hand-held. Devices with big sizes are excluded. For example, the balloon-like haptic device in [25] is too big to hold in hand.
- The shape and size are similar to mobile devices [26]. Or the prototype could be imagined as mobile devices [27], [28], [29], [30], [31].
- Although the prototype may not look like a handheld one, the authors mentioned the prototype was developed for mobile communication [32].
- When wearables are used together with the mobile device, the haptic stimuli should present to hands [5], [15], [16] rather than wrists [33], [34] or shoulder [35], or other body parts [36], [37], [38], [39], [40], [41], [42], [43] because the density of tactile sensors in the skin over the entire body is different [44], [45]. We need to limit the

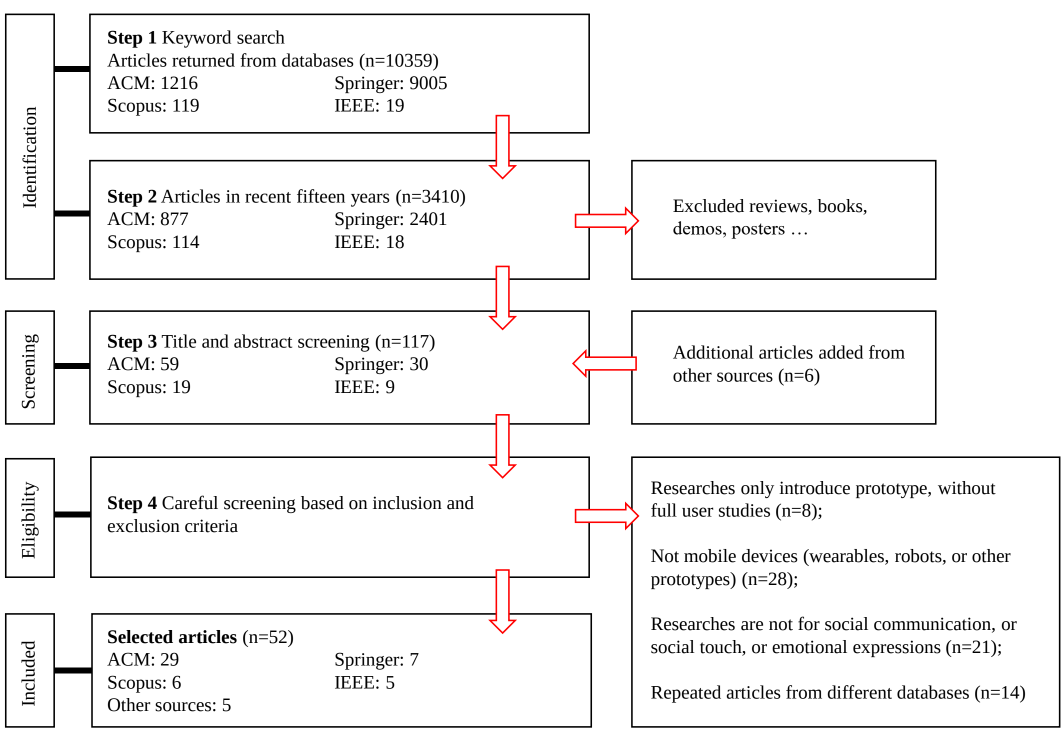

Figure 1. The flow chart and detailed steps for literature search

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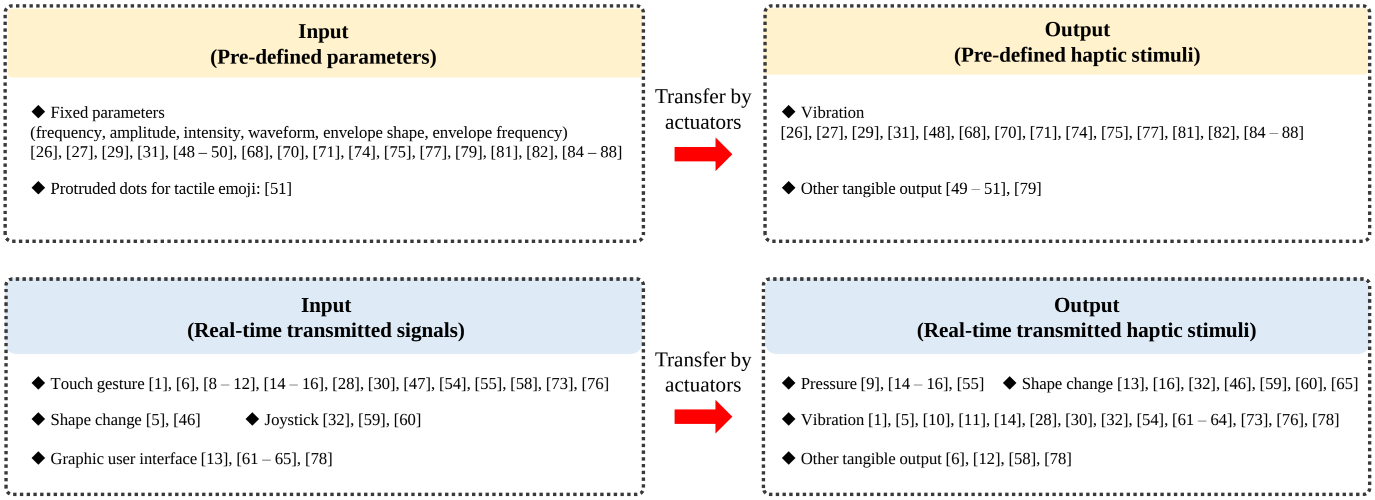

Figure 2. Typical haptic input and output

research area to the hand to facilitate the later discussion.

- Some studies used computers for video calls and haptic prototypes for remote touch transmission. These studies could be included because we could use a mobile device to replace the computer for video calls, e.g., Skype for video calls on mobile phones [5], [11]. The results of these studies are meaningful in MST for mobile devices.

We also found two types of studies: computer-mediated human-to-human interaction (HCH), which in our case involved mobile devices, and human-to-computer interaction (HC), also carried out using mobile devices. For HCH studies, researchers mainly tried to transmit MST signals via mobile devices in remote communication. One dyad is needed in the HCH studies. For studies such as [46] and [47], some participants were asked to create emotional expressions on a mobile device while others were asked to recognize user-defined emotional expressions after a while. Although the communication is not real-time, we kept these studies for further analysis since there is an expressing and perceiving process from one dyad.

For HC studies, researchers primarily designed haptic stimuli for emotional expressions and tested the perceiving of haptic stimuli when one participant interacted with the mobile device. Although it seems no dyads were in HC studies, we still included them in this paper because of the following reasons:

1) Participants interact with the mobile device and perceive the haptic stimuli conveying emotional expressions. It can be assumed that the haptic stimuli are sent by other people. For example, we could assume that the researcher customizes the haptic stimuli with intended expressions and send them to the participants to perceive.
2) The research results were meaningful for future HCH studies. For example, Yoo et al. [48], and Salminen et al. [49], [50] tested how the designed haptic stimuli represented emotional expressions. These haptic stimuli could be directly applied in an application for social communication. The research field can easily broaden from HC to HCH.

3 Results

We selected 52 articles for further analysis. Figure 1 shows the search results in each step. The **Appendix** shows detailed information about these selected articles.

3.1 Design: from haptic input to haptic output

This section summarizes the typical haptic input and output found in the selected papers. We also study how researchers set parameters for haptic stimuli based on the selected actuators to express certain social touch.

3.1.1 Typical haptic input

There are two types of haptic input signals: pre-defined signals and real-time generated signals. Figure 2 shows a summary of typical haptic input and output.

Researchers usually set parameters (e.g., frequency, amplitude, envelope shape, envelope frequency, waveform, etc.) for pre-defined signals, and users receive the preset haptic stimuli. For example, Shiraga et al. [26] used 85 pre-defined haptic stimuli with various accelerations, intensities, and voltages and quantified how those haptic stimuli affected users' impressions. Choi et al. [51] defined protruded dots as tactile emoji for visually impaired people to perceive.

The real-time signals can be generated based on the social touch properties (e.g., pressure, duration, gesture patterns, etc.) [52], which means, for example, when one user applies changing pressure during a touch, the other can feel the real-time changing pressure by haptic signals. We summarized four main types of haptic input for the real-time generated signals: touch gestures, shape change, joystick, and graphic user interface (GUI).

3.1.1.1 Touch gestures

We found that researchers mainly converted collected sensor signals from different sensors to haptic stimuli. Some researchers mainly used force sensor resistors (FSR) to collect the force data and convert it into haptic stimuli via different actuators. For example, Kissenger [8], [9] applied FSR to collect the user's force when kissing, transferred the force data, and presented the force with stepper actuators (Figure 3(a)). The converting equations can be found in [53]. Other studies that apply FSR to collect force data are [1], [14], [28], [30], and [54]. Besides FSR, Zhang et al. [15] developed an Android application to detect the movement of touch on the mobile phone and converted the collected data to haptic stimuli. Zhang et al. [55] used a silicon surface with an airbag for social touch input (Figure 3(b)). The force applied to the silicon surface is measured by the air pressure change of the airbag [55].

Some researchers converted audio signals to haptic stimuli. For example, Furukawa et al. [12] developed a tactile screen for bidirectional tickling (Figure 3(c)). They used an audio signal to provide proportional modification of the velocity of the index finger movement on the screen [12]. Two audio amplifiers were applied to drive the vibrators embedded in the tactile screen. Other examples that convert audio signals to haptic stimuli are [10], [11], [56], and [57].

Other researchers applied more than one type of sensor (e.g., force sensors and acceleration sensors.) to collect various signals and convert them into haptic stimuli. For example, the prototype in [58] has a force sensor and an acceleration sensor. The value of force and acceleration were sent to a control box with a microprocessor and stereo amplifier. This control box converted the collected sensor data into haptic stimuli.

3.1.1.2 Shape change

Researchers usually applied flex sensors embedded in the haptic device to detect the shape parameters, such as the amount of flex. For example, Strohmeier et al. [46] designed a shape-changing interface to communicate emotions (Figure 3(d)). The shape parameters of this interface are convexity, angle, radius, axis, granularity, speed, area in motion, and amplitude of motion [46]. Users could create shapes with different shape parameters to express various emotions [46]. Besides, Singhal et al. [5] also converted shape parameters into other haptic stimuli. For example, the Flex glove developed in [5] could provide vibrotactile stimuli by an LRA based on the signals collected from flex sensors.

3.1.1.3 Joystick

Researchers usually developed haptic devices with joysticks and used the joystick for movement input. The joystick input values could be read, usually through a Bluetooth module [32], [59], [60] connected to a computer. For example, Park et al. designed Wrigglo [60], controlled by joysticks attached to a phone case (Figure 3 (e)). Users could manipulate the joystick to control the directions of the other joystick attached to the other user's phone case.

3.1.1.4 GUI

Researchers developed mobile applications in which users could customize the touch signals and send the touch signals to the haptic device [13], [61], [62], [63], [64], [65]. For example, Jowalski et al. [62] developed Cubble with a haptic device and a mobile application. Users could send touch signals such as nudging, tapping, and holding hands to the haptic device from the mobile application (Figure 3(f)) [62].

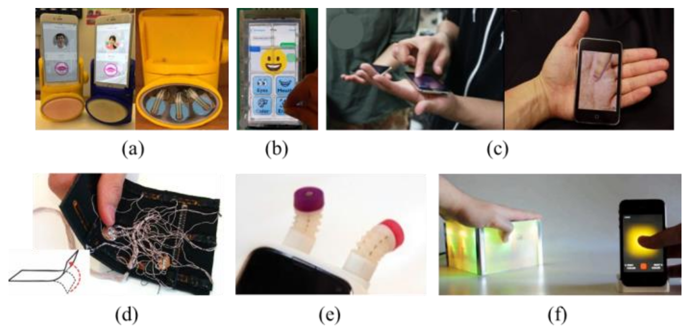

Figure 3. (a) Kissgenger with stepper motors [9]; (b) In-Flat with airbags [55]; (c) KUSUGURI [12]; (d) A shape changing interface [46]; (e) Wrigglo with joysticks [60]; (f) Cubble with vibration actuators [62]. Figures are from the corresponding literature.

3.1.2 Typical haptic output based on different actuators and parameters

Shape change, pressure, vibration, and other tangible output are typical haptic output. We describe how typical actuators can render them in selected papers. The **Appendix** shows actuators and related parameters for presenting social touch.

3.1.2.1 Shape change

The mechanical arm motion of an arm-like haptic device could control shape change. For example, Suzuki et al. [65] controlled a two degrees of freedom (DOF) arm with haptic motors to present stroking and patting (Figure 4(a)).

Haptic actuators such as servo motors, allowing specific positions [13], can control the shape change. For example, five servo motors are arranged in MobiLimb to provide 5-DOF [13], for creating in social touch such as stroking, patting, and other tactile stimuli on the hand or wrist to convey emotions (Figure 4(b)) [13].

The shape memory alloy actuation (SMA) coil can also control the shape change. For SMAs, there are solid-state phase transformations when heated, leading to macro-scale shape changes [16]. For example, Bendi applied six coil-type SMAs [59]. Users can use a joystick to control the shape change of Bendi, which supports bending, tilting, and shrinking movements when electrical signals flow on the specific SMAs (Figure 4(c)) [59].

3.1.2.2 Pressure

Stepper motors allow a surface to extend and contract linearly to present the touch and pressure [9]. For example, an array of linear stepper motors in Kissenger [9] can generate normal forces on the skin surface by changing the shape and positions of the Kissgener surface (Figure 3 (a)).

Inflatable airbags could generate pressure. For example, Zhang et al. [15] designed SansTouch to reproduce skin-like touch sensations. They applied inflatable airbags in a wearable hand sleeve that can generate touch pressure on the user's hand (Figure 4 (d)) [15].

SMAs can also create pressure. It has been demonstrated that forming SMAs into fully-compacted, tightly wound springs can produce significant forces [16], [66]. For example, Yarosh et al. [16] applied SMA compression in wearable gloves such as SqueezeBands to transmit MST signals.

3.1.2.3 Vibration

Vibrations are composed of vibrating components that deliver information through temporal parameters in the signals, such as amplitude, duration, carrier frequency, envelope shapes, frequency of envelope, and waveform compositions [67]. Thus, researchers usually directly choose the parameters of the vibration waveform to provide expected effects. For example, Wei et al. [68], [69] and Zhang et al. [70] applied an LRA, and they chose frequencies, durations, amplitudes, envelope shapes, and other temporal parameters to generate social touch for emotional expressions. An et al. [71] used vibration patterns from VibViz – a vibration library [72] with varying parameters, which could be presented by the Taptic Engine embedded in iPhone to express emotional expressions.

The voice-coil motor is another type of vibration actuator being used frequently. For example, Ju et al. [73] used a TECHTILE toolkit which contained voice-coil vibrators to provide vibrations. MacDonald et al. [31], Yoo et al. [48] (Figure 4 (e)), [74], and Wilson and Brewster [75] (Figure 4 (f)) applied the Haptuator actuator to the mobile device. Heikkinen et al. [76] (Figure 4 (g)) and Seifi et al. [27] applied the C2 actuator to the mobile device, using its audio output through an amplifier and providing vibrations for affective communications.

There are many other types of vibration actuators, such as Minebea Linear Vibration Motors (LVM8 [1], [28], [29], [30], [76]), DC motors [77], Eccentric motors, Eccentric rotating mass vibration motors [78], [79], [80], and other types in [26], [61], [62], [63], [64], [81], [82], [83], [84], [85], [86], [87]. The most common way to create certain social touch in these studies is to control the temporal parameters.

3.1.2.4 Other tangible output

Various haptic systems and actuators, such as electrotactile systems, ultrasonic systems, and linear electro-mechanical actuators, provide other tangible outputs for touch sensations.

The electrotactile system can generate touch sensations by passing a small electric current through the skin [67]. Usually, researchers control the current and voltage of the related piezoelectric and electromagnetic actuators, to produce certain social touch (e.g., tickling [12]) for emotional expressions [49], [50].

The ultrasonic system can also provide tactile sensation. For example, Hashimoto et al. [58] choose the frequency and the amplitude of the waveform to control the suction or pushing pressure of social touch gestures, which can transmit tickling, tapping, pushing, and caressing on their palms from the air (Figure 4(h)).

Linear electro-mechanical actuators can also provide tactile sensation. For example, the table version of EnPower [78] applied this actuator to provide a specific tactile pattern following the Braille protocol for the deafblind (Figure 4(i)).

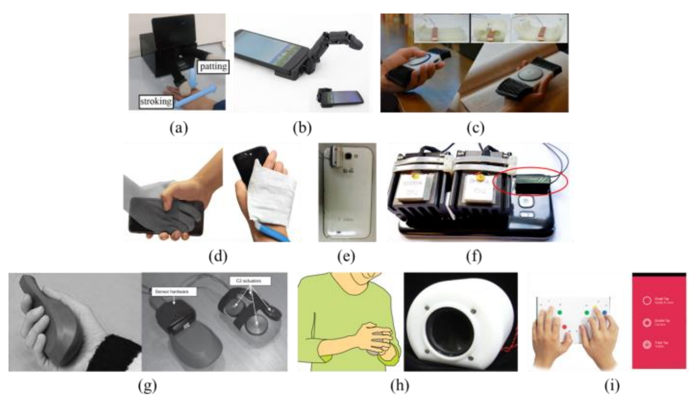

Figure 4. (a) A haptic device presenting stroking and petting [65]; (b) MobiLimb with servo motors [13]; (c) Bendi with SMAs [59]; (d) SansTouch with inflatable airbags [15]; (e) A mobile phone with a voice-coil motor [48]; (f) Multi-moji, a mobile phone with a Haptuator [75]; (g) A haptic device with C2 actuators [76]. (h) A tactile display with ultrasonic system [58]; (i) EnPower table version with linear electro-mechanical actuators [78]. Figures are from the corresponding literature.

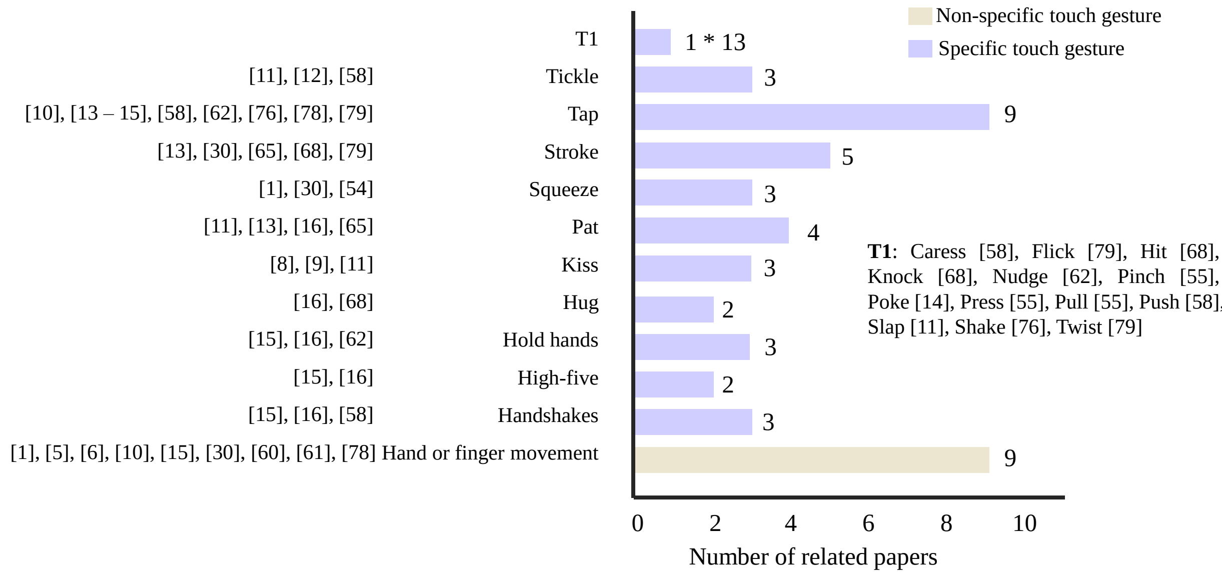

Figure 5. Overview of mediated social touch gestures studied in the selected papers. Thirteen MST gestures categorized as T1 were exclusively studied once across the relevant papers.

3.1.3 Mediated social touch

We summarize the MST gestures from the selected articles in Figure 5. For some studies designed with more than one touch gesture, we listed every social touch gesture in the corresponding category. For example, Brown et al. [79] designed stroke, tap, flick, and twist. We list them separately in Figure 5.

There are two types of social touch gestures: specific and non-specific. Specific touch gestures usually have names and definitions, such as “Tickle” and “Stroke”. Non-specific touch gestures do not have a specific name or definition. Researchers usually described the hand or finger movement [6] for non-specific touch gesture. For example, Mullenbach et al. [6] used the TPad tablet and developed Haptic Virtual Touch to make users see and feel the real-time finger path of the other user (Figure 6). They used ‘a haptic rendering of their partner’s finger’ to describe the non-specific tough gestures [6].

Figure 6. The TPad tablet [6].This figure is from [6].

We found that many studies designed touch signals for ‘tap’, ‘kiss’, and ‘stroke’. The reason could be that users frequently used those social touch gestures in mobile communication. Another reason could be that those social touch signals are easy to design.

Some social touch gestures were less studied. For example, ‘Shake’ and ‘Flick’ were only studied by [76] and [79], respectively. One reason could be that users may seldom use these social touch gestures. Another reason could be the technical limitations. For example, on the one hand, it is not easy for researchers to design ‘hold a finger’ since the mobile device is like a brick rather than a finger. On the other hand, if researchers only have the vibration technology, it is not easy to use only vibration to express ‘hold a finger’.

Figure 5 also shows that researchers studied more specific touch gestures with haptic stimuli on mobile device than the non-specific ones.

3.1.4 Emotion that social touch communicates

Hertenstein et al. [23], [88] have demonstrated that touch communicates emotion. MST gestures by haptic stimuli could also communicate emotion [1], [17]. For example, Ju et al. [73] developed a haptic prototype. They asked participants to perform different social touch gestures (e.g., tap, rub, press, etc.) to express emotions such as joy, anger, sadness, and relaxation.

We summarize the emotions that social touch communicates in Figure 7. For studies that use social touch to communicate more than one emotion, we listed every emotion in the corresponding category. For example, Réhman and Liu [77] tested Normal, Happiness, Surprise, and Sadness. We listed them separately in Figure 7.

We summarize the following two types of emotions that social touch communicates:

Dimensions. Many researchers designed MST signals to communicate emotions. But they did not refer to a specific emotion. Instead, they use the dimensions of emotion. These

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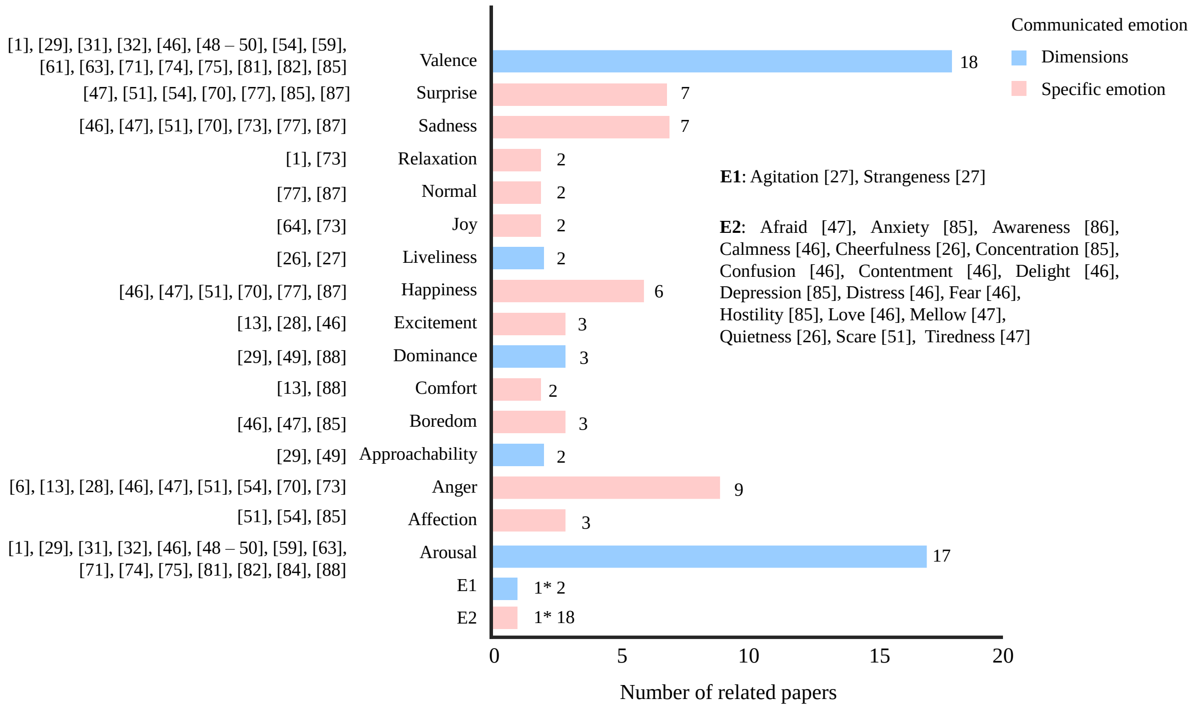

Figure 7. Overview of emotion that social touch communicates studied in the selected papers. Two emotions, categorized as E1, belong to the dimension category, while eighteen emotions categorized as E2, representing specific emotions, were each exclusively studied once across the relevant papers.

dimensions are arousal, valence, and dominance [89], approachability [90], agitation, liveliness, and strangeness [91].

Specific emotion. Some researchers directly design haptic stimuli to communicate a specific emotion. For example, Strohmeier et al. [46] and Ju et al. [73] specifically mentioned they design haptic stimuli for anger.

For emotion dimensions, there are several terms representing the similar dimension. Barrett and Russell [92] show the various sets of terms for the two-dimensional structure of affect. We need to integrate similar terms to simplify Figure 7. We integrated similar terms into one. We integrated the pleasantness and unpleasantness [1], [29], [49], [50], [81], positive and negative [59], [61], active pleasure and inactive pleasure [85] into the valence dimension based on [89], [93], [94], [95]. We integrated the calm [81] into the arousal dimension based on [95]. We integrated the weak and strong emotions [59] into the dominance dimension based on [96].

Figure 7 shows that most researchers used the emotion dimensions to describe an emotional feeling when the emotion is difficult to describe. The emotion dimension coordinate [89], [92] could clearly show what the haptic stimuli could communicate. For example, Yoo et al. [48] connected the parameters of haptic stimuli with emotional expressions so that they could quickly choose the parameters for haptic stimuli to communicate the targeted emotion.

3.2 Prototypes

This section presents an overview of the prototypes that researchers developed to transmit and present MST signals as described in the selected papers. We summarize three prototype categories: integrated actuators, accessories, and connected devices (C1-C3).

3.2.1 Integrated actuators (C1)

In C1, researchers try to attach the actuators to a mobile device [10], [11], or make use of embedded actuators in the mobile device [6], [54], [71], [82] to present MST signals. Figure 8 shows typical examples of C1.

Related prototypes in C1 include Kissenger [8], CheekTouch (Figure 8 (a)) [10], [11], KUSUGURI (Figure 3(c)) [12], Multi-moji (Figure 4 (f)) [75], VibEmoji (Figure 8 (b)) [71], Haptic Empathy [73], PDA [85], CoupleVIBE [86], Shake2Talk [79], [80], iFeeling [77], [87], Pressages [54], TPad [6], emoji icons [68], [70], Nokia tablet [49], [50], Vivitouch [81], Nexus One (Figure 8 (c)) [82], PalmScape (Figure 8 (d)) [84], Bendi (Figure 4 (c)) [59], a haptic device expressing emotional intensity by gestures [47], a smartphone with a vibrotactile actuator [64], [74], a Pad-like touchscreen [48], [97], a mouse-like haptic device (Figure 8 (e)) [29], a shape changing device [46], a haptic device presenting protruded emoji for visually impaired people [51], and other handheld haptic devices (Figure 8 (f)) [26], [31].

The advantages of this type are as follows:

- The research results of the above-mentioned prototypes can be directly applied to future mobile phones when the

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technology is mature. The research results in these studies will also be meaningful at that time. For example, Yoo et al. [48] attached the vibration actuators on the back of the mobile phone (Figure 4 (e)), and they studied how the vibration parameters affect the emotional expressions of vibrotactile stimuli. Park et al. [10], [11] placed vibration actuators on a thin acrylic panel (Figure 8 (a)). The thin acrylic panel was attached to the mobile phone, which did not change the shape and the use of the mobile phone (Figure 8 (a)).

- Developing these prototypes is convenient and cheap because no accessories or connected devices are needed. If the mobile application enters the market, the user does not need to pay an extra fee for additional products.

Figure 8. Typical examples of C1. (a) CheekTouch with attached actuators [10], [11]; (b) An iPhone with an embedded Taptic Engine for VibEmoji [71]; (c) The Google developer phone Nexus One with an embedded vibration actuator [82]; (d) PalmScape with four vibration actuators [84]; (e) a mouse-like haptic device with vibration actuators [1], [28], [29], [30], and [76]; (f) a handheld haptic device with a vibration actuator [26]; Figures are from the corresponding literature.

3.2.2 Accessories (C2)

In C2, researchers designed accessories and attached them to the mobile device. Figure 9 shows typical examples of C2. Usually, the mobile device is used for verbal communication, such as voice calls and video calls, while the attached accessory is used to present social touch. For example, Zhang and Cheok [9] developed Kissenger and attached it to the mobile phone. Users use the mobile phone for voice or video calling when sending kissing by the attached Kissenger (Figure 3 (a)).

Related prototypes in C2 include Kissenger [9], MobiLimb [13], POKE [14], In-Flat [55], and Wrigglo [60].

There are differences between C1 and C2. The attached actuator in C1 could be embedded in the mobile device when the technology is mature. However, the accessories in C2 are not easy to be embedded in the mobile device, especially when the accessories are used to produce movements. For example, Teyssier et al. [13] developed MobiLimb and attached it to the mobile phone to produce certain movements (Figure 4 (b)). It is not easy to embed MobiLimb [13] in mobile phones.

The advantages of the attached prototype are as follows:

- These accessories are usually developed to be compatible with existing mobile phones. They could provide richer touch effects without changing the main body, the existing sensors, or the actuators of the mobile phone. For example, POKE [14] can provide vibrations and force feedback by inflatable surfaces with air bumps (Figure 9). The force feedback cannot be presented by the mobile phone itself without the air bumps.
- Researchers could design various shapes and movements and choose suitable materials for the accessories to transmit MST signals. For example, the Kissenger [9], [53] was attached to the mobile phone. Users can send and perceive kissing via the attached Kissenge. The shape and materials of Kissenger make it more acceptable to touch the lips than a mobile phone. MobiLimb [13] is a small limb-like accessory which can be attached to a mobile phone. Users can modify the shapes and movements of the limb by controlling the angular position of servo motors to touch the user's hands or wrists. In-Flat [55] is an inflatable skin-like silicon overlay for smartphones, which consists of airbags (Figure 3 (b)). It could present various shapes of airbags and skin-like touch sensations with several complicity levels of the surface. Wrigglo [60] is an accessory attached to a mobile phone case (Figure 3 (e)). Users can manipulate the joystick of the phone case and make the Wrigglo shrink or bend in different directions.

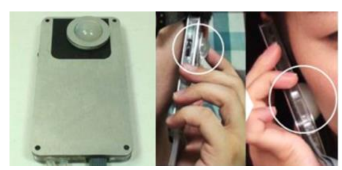


Figure 9. Typical examples of C2: POKE attached to a mobile phone [14]; Figures are from the corresponding literature.

3.2.3 Connected devices (C3)

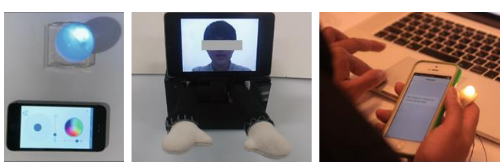
Researchers designed haptic devices that connected to mobile devices in C3. Mobile devices are generally for verbal communication [58], [59], [65] or customizing MST signals [61], [62], [78], while the connected devices are for presenting MST signals. Figure 10 shows typical examples of C3.

Related prototypes in C3 include Sphero mini (Figure 10 (a)) [61], little hands (Figure 10 (b)) [65], Cubble (Figure 3 (f)) [62], a ball-shaped device [58], Kissenger [8], a ring-shaped device (Figure 10 (c)) [63], EnPower [78], Flex-N-Feel [5], SansTouch (Figure 2.4 (d)) [15], SqueezeBands [16], and EMO [32].

There are differences between C3 and C2. The accessories need to be attached to a mobile phone in C2. However, it is not necessary to attach connected devices in C3 to a mobile device.

The advantages of connected devices are as follows:

- Researchers and designers have more opportunities to design a more anthropomorphic touch. For example, in [65], researchers directly develop a hand model (Figure 10 (b)) to send stroke and pat, which is very similar to real hands. SansTouch [15] and SqueezeBands [16] can provide the force of holding hands and handshaking. Flex-N-Feel [5] can make people feel the flexing of the remote partners' fingers.
- Connected devices can adapt to more mobile devices. For example, accessories such as the attached Kissenger [9] were limited to the smartphone because of its shape. It was no longer helpful if users used a tablet with a bigger screen. However, the connected Cubble [62] can adapt to both smartphones and tablets (Figure 3 (f)).
- It can be applied to more target user groups. It is generally difficult for visually impaired people to contact others by mobile phone. Researchers could design various haptic devices based on their demands to touch others remotely and connect those haptic devices to mobile devices. For example, EnPower is designed for visually impaired people [78]. A special tablet and a wearable were designed and connected to a mobile phone for them to touch others remotely.



(a) (b) (c)

Figure 10. Typical examples of C3. (a) Sphero mini with a mobile phone [61]; (b) Two little hands with a tablet [65]; (c) a ring-shaped device with a mobile phone. Figures are from the corresponding literature.

3.3 Evaluation

We summarize the evaluation parts of the selected papers in terms of participants, experiment design, and data collection. The detailed information is in the **Appendix**.

3.3.1 Participants

There are four types of relationships among participants in the selected papers:

- Close relations (couples [1], [6], [8], [9], [10], [14], [54], [59], [62], [64], [79] or friends [1], [5], [16], [60], [64], or family members [16])
- Strangers [6], [9], [12], [15], [16]
- Participant interacting with researchers [11], [26], [27], [28], [29], [31], [48], [49], [50], [51], [63], [65], [78], [73], [74], [75], [76], [77], [81], [82], [84], [85], [87], [97]
- Participant interacting with virtual agents [13], [30], [68], [70]

There are some notes when categorizing the relationship of participants. If the researchers mentioned the participants were couples or friends, we regarded them as close relations. If researchers did not mention those participants were known to each other, we regarded them as strangers.

For participants interacting with researchers, there are two types: 1) the researchers and the participants were engaged in real-time communication, such as [63], [65], [78]; 2) The researchers created haptic stimuli and participants perceived them.

3.3.2 Experiment design

We summarized five types of experiment design and test methods as follows:

With and without touch + other variables. In this type, researchers usually designed haptic stimuli for MST gestures and tested if adding the MST signals was beneficial for users. Besides the existence of MST signals [15], [71], researchers also considered other variables, such as gender [9], [65], emotion contexts [16], communication partner [6], temperature [75], environment [82], physical parameters [50], device types [9], multimodal feedbacks [11], [28], [50], [54], [63], [74] (study 3), and communication mode [8]. Usually, researchers used the mixed experiment design.

With touch + other variables. In this type, the haptic stimuli were presented to participants, and researchers tested other variables such as communication concepts [62], emotion state [64], emotional intensity [47], gesture and role [1], gesture, actuators, and scenarios, preset haptic stimuli and communicated emotion (dimension) [73], [74], [77], [84], [85], [87], impressions [26], emoji [68], [70], meaning [31], design foundation [29], and message intention recognition [51].

Field study + interviews. In this type, participants usually joined a field study to try the new prototype for a longer term. After the field study, an interview was needed to express their experiences. For example, in Bales et al. [86] studied how couples use CoupleVIBE in their daily lives by inviting seven couples into a 4-week field study. Three couples used ForcePhone for Pressages for one month [54]. In [10], couples had a phone call using CheekTouch for 20 minutes per day for five consecutive days. Seven couples used Bendi to communicate for three days in the coffeehouse [59]. Three couples used POKE for one month [14]. Other examples are five days in [64], a four-week trial [71], a six-week trial in [9], and two weeks in [79].

Interviews. In this type, participants usually used the prototype during the user study and gave feedback about the user experiences. For example, participants in [28], [54], [60], [61], and [78] expressed their overall impressions and their points of view on the interaction about the new prototype. Free comments were also welcome during the interview in [1], [12], [13], [14], [15], [30], [55], [58], [59], [70], [86].

Semi-structured interviews were also popular. For example, in [5], besides the preference and emotions when using the glove, participants also answered how they would like to use the glove in their relationship. In [1], the sender was asked to choose which touch gesture was suitable for expressing each emotional intention. Other examples are [9], [62], and [76].

Varying parameters and corresponding haptic effects. In this type, researchers usually vary the parameters and test how participants perceive haptic stimuli changes. For example, Yoo et al. [48] set five amplitudes, five carrier frequencies, six durations, and six envelope frequencies for haptic stimuli. They explored how those parameters affect the affective ratings in the emotion model [48]. Besides, Salminen et al. [49] tested amplitude, rise time, and burst number of haptic stimuli. They explored if perceiving these haptic stimuli was significantly different in different contexts such as laboratory and bus travel [49]. Furthermore, Strohmeier et al. [46] tested how the shape parameters, such as the amount of bend or flex, affected the affective ratings in the emotion model. Other examples are [27], [31], [81], [97]. Those studies tested how parameters, such as frequency, amplitude, duration, waveform, duty ratio, and rhythms, affected the affective ratings in the emotion model.

3.3.3 Data collection

There are two types of data: objective data and subjective data. We summarize and list the collected data as follows:

There are three types of objective data:

- **Observation results**: behavior analysis [8], [12], speech turns – temporal structure of the dialogue, and touch behaviors – occurrence and duration [61], touch gestures [1], [76], [10], [15], shape gesture [46], haptic messages created by participants (gesture patterns) [30], verbal content [61], facial expressions [12], [77], [87] number of actions [65], attempted touch [16], and number of places tagged [86].
- **Recorded objective data**: working time [65], task speed [54], presage log [54], logged graphs and audio recorded data [14], logged content of each message (meaning type, color, and if applicable the tap pattern) [62], how many, when and by whom the message was sent [62], which device was used [62], location of the contact area and intensity of the gesture [32], action, velocity and abruptness (gesture) [32], usage minute [14], gesture length [47], pressure [47], and speed message [47], reaction time [77], delay time [87], effectiveness (the success to failure ratio for task completion) [77], and movements (accelerometer, magnetometer, gyroscope) [76].
- **Calculated data**: error rate [54], [87], recognition accuracy [47], [46], [51], [87], and winning rate in games [9].

There are five types of subjective data:

- **Likert scale**:

  Five-point Likert scale: ease of use [6], fun [6], self-expression [6], understand partner [6], and how similar it was to the real touch [15]. Intimacy [5], emotional connection [5], closeness [62], appropriateness (doesn't fit at all and fits very well) [82], score the touch [11], feels like the specific touch [68], enhance the effect of text / stickers [68], and impressions [26].

  Seven-point Likert scale: enjoyment, boringness, and willingness to friendliness, trust, and authority [65], preference [13], useful [13], amusing [13], affectivity [8], co-presence[8], lively [27], agitating [27], strange [27], satisfaction (comfort and acceptability) [77], [87], easiness [76], understandability [76], reasonability [76], and general experiences [71].

  Other Likert scales: acceptance [64], scored how strongly the vibrations evoked each emotion or sensation on a scale of 0 to 6 [85], difficulty rating survey (how difficult to determine each emotion conveyed by vibration, scale 1-5) [73], usefulness, easiness-to-use, efficiency, pleasurability, and willingness to use [32].
- **Bipolar rating scales and semantic differential questionnaire**: friendly and co-operative/hostile and competitive, intense/superficial, socioemotional/task-oriented, informal/formal, ranging from -4 to +4 [28]; pleasantness (unpleasant/pleasant), arousability (calm/arousing), approachability (avoidable/ approachable), dominance (I was in control/The stimulus was in control), ranging from -4 to +4 [49]; relaxing/arousing for the message, aroused/relaxed for the sender felt, ranging from -4 to +4 [1]; three sensory (week/strong, smooth/rough, non-rhythmic/rhythmic) and two affective (calm/alarming, unpleasant/pleasant), ranging from -2 to +2 [81]; applicability (inapplicable/applicable), easiness (difficult/easy), pleasantness (unpleasant/pleasant), expressiveness (weak/strong), and reasonability (unreasonable/reasonable), ranging from -4 to +4 [30]; arousal, comfort, preference, familiarity, and dominance, ranging from -3 to + 3 [97].
- **Ranking**: Pleasantness [50].

- **Verified questionnaire**: NASA task index (NASA-TLX) [16], Networked minds measure of social presence NMMSP [16], SAM [29], [31], [46], [48], [63], [74], [75], [82], [84], the Russell's circumplex model of affect [73], SEA scake (Subjektiv Erlebte Anstrengung) [82], Hassenzahl's AttrakDiff questionnaire [9], 18-item Semantic Differential Scale by Mehrabian and Russell (from [98]), [9], an 18-item rapport questionnaire [54], satisfaction: 7-item Relationship Assessment Scale (from [99]) [9], and perceived stress: the 10-item Perceived Stress Scale (PSS) (from [100]) [9].
- **Interview**: semi-structured interview [1], [5], [9], [62], [76], and free comments [1], [12], [13], [14], [15], [28], [30], [32], [54], [55], [58], [59], [60], [61], [70], [78], [86].

Based on the above, we found researchers mainly collected data in four aspects: user's behavior, biological data of user behavior, subjective ratings, and personal comments. It suggests that applying both quantitative and qualitative analysis can provide comprehensive insights when developing MST signals on the mobile device. Still, researchers could choose the most efficient ways based on their needs.

3.4 Research findings of selected papers

We reviewed the selected papers and summarized the research findings in this section.

3.4.1 Signal design

1) Pre-defined signals with temporal parameters

Researchers have found that parameters such as amplitude [48], [85], [97], carrier frequency [48], [81], envelope shapes [50], [85], envelope frequency or rhythm [26], [48], [81], [82], [85], [97], duration [48], and intensity [26] significantly affect affective responses [97] of haptic icons [48], affective ratings [81], affect impressions of haptic stimuli [26], [82]. We summarize the parameters and perceiving of haptic stimuli from the following aspects:

- **Amplitude**. Amplitude has been found positively affects arousal [48], [49], [97] and dominance [49], [97]. However, it has also been demonstrated that amplitude has a negative impact on several other dimensions, including pleasantness [49], comfort [97], preference [97], and familiarity [97].
- **Carrier frequency**. The carrier frequency of vibrations positively affects the perceived valence [48] of the haptic stimuli. Specifically, low-frequency vibrations may incur negative feelings, such as unpleasantness and roughness, while high frequency vibrations are associated with positive ones, such as pleasantness and smoothness [48]. Additionally, the carrier frequency also significantly influences the ratings of calmness or alarm, indicating a main effect of frequency on these dimensions [81].
- **Envelope shape**. Haptic stimuli with long rise time are perceived as more pleasant [50], [85] and arousing [50]. Additionally, vibration patterns with waveforms falling near the end lead to 'inactive pleasure' [85].
- **Envelope frequency and rhythm**. The envelope frequency negatively affects arousal [97], valence [48], dominance [97], pleasantness [82], and effectiveness [97], particularly in the low-frequency range of 0 to 16Hz [48].
- **Duration**. Longer durations of haptic stimuli increase arousal [48], [82]. The very short and subtle haptic stimuli are the most pleasant and least arousing [82].
- **Intensity**. Stronger vibrations are perceived as more alarming [81], more arousing [82], and more powerful [26]. Haptic stimuli with some suspension intervals are rated as more powerful, while those with gradual intensity changes but no suspension intervals induced a heavier impression [26].

We found that most studies evaluate how temporal parameters of haptic stimuli affect emotional expressions, but few focus on the design and evaluation of individual pre-defined MST signals. Future designs could consider the detailed temporal parameters as a helpful guideline for designing MST signals.

2) Real-time generated signal

In the evaluation of real-time generated signals, Strohmeier et al. [46] and Hannan et al. [47] evaluated how well users could recognize the emotional expressions defined by other users via mobile devices. Hannan et al. [47] asked participants to draw on the touchscreen to express different emotional intensities, and after a week, they were asked to recognize the emotional intensity they had previously drawn. It was found that participants could recognize more emotional intensities at extreme ends and could achieve higher recognition accuracy for their own gestures than others' gestures [47]. Size and pressure were two factors that could be interpreted more, while it was not easy to differentiate the speed [47]. Strohmeier et al. [46] asked participants to express emotion by the curve surface. For example, most participants use concave U shape to express delight and happiness. And other participants were asked to recognize those curve surface patterns. The recognition results showed that shape parameters affected the positive-negative dimension of emotion [46], while related movement parameters affected arousal level [46].

Salminen et al. [29] introduced different generative methods for real-time generated signals. They compared two methods of extracting tactile signals: one is extracting from concurrent speech samples, while the other one is extracting from separate speech samples with static vibrations. The results showed that using static vibrations alongside speech resulted in higher ratings of pleasantness and approachability compared to the other method [29].

We did not find many studies evaluating the generative methods of the real-time touch in mobile communication. In contrast, most studies prefer evaluating the application of real-time generated signals in mobile communication. However, evaluating the generative methods could provide deeper insight into MST signals and make them better match related MST gestures. Thus, studying the generative methods could be a research direction.

3.4.2 Multimodal stimuli

Researchers usually design multimodal stimuli for mobile communication and evaluate the effects of different types of stimuli, including haptic, auditory, or visual, as well as different combinations of these stimuli.

We summarized the following types:

- **Visual + haptic stimuli**. The added haptic stimuli help to increase the expressiveness of visual information [70], prime the emotion of a text message [63], and enrich the visual perceptions [55].
- **Visual + haptic + thermal stimuli**. The combined multi-modal stimuli increase the available range of emotional states [75].
- **Speech + haptic stimuli**. Adding haptic stimuli to speech is more arousing and dominant than the speech-only stimuli [29]. Haptic stimuli can resolve conversations smoothly by replacing words, making people concentrate more on phone conversations [14].
- **Haptic + auditory stimuli**. Park et al. [11] compared multimodal stimuli when transmitting MST signals such as pat through CheekTouch. The results indicated that using haptic stimuli combined with sound was the most effective way to deliver a pat [11].

We found many studies had demonstrated that multimodal stimuli could enhance mobile communication. However, these studies mainly evaluated the difference between multimodal and single-modal stimuli. They did not evaluate the stimuli effectiveness of different modalities.

For future research, multimodal stimuli are still a promising research direction. Making the different modalities well match each other is also important in design.

3.4.3 Evaluation of gestures

Evaluating gestures is an active area of research in the field of mobile communication. One popular way of generating haptic stimuli is by performing gestures on a mobile device [101]. Users often have their preferred gestures when interacting with haptic devices. For example, Rantala et al. [30] designed a new touch prototype. The user study revealed that participants preferred squeezing and stroking when interacting with the device [30]. Heikkinen et al. [76] used the same prototype as [30] and indicated shaking, smoothing, and tapping were the most popular gestures.

Users often have their preferred gestures when expressing intended information. For example, Rantala et al. [30] found using squeezing gestures was a quick way to create haptic messages, while stroking gestures helped express more detailed ones. Similarly, Heikkinen et al. [76] showed that users could apply spatiality in haptic messages, using the forward-backward gesture to indicate agreement. Participants particularly appreciated the spatial haptic output when utilizing stroking gestures [30]. Furthermore, Rantala et al. [1] applied the same prototype and explored how different gestures could be used to communicate various emotions. The results indicated that participants preferred using squeezing gestures to communicate unpleasant and aroused emotional intentions [1]. On the other hand, they thought using finger touch gestures was better in communicating pleasant and relaxed emotional intentions [1].

We found that researchers mainly focused on identifying users' preferred gestures when interacting with mobile devices to convey the intended information. The intended information was often limited to the emotional dimension. However, there is a need for more comprehensive research on gestures in mobile communication since Jung et al. [102], [103] have demonstrated that a detailed investigation of gestures can establish foundational principles for MST gesture design and enable automatic detection and recognition.

3.4.4 MST signals in mobile applications

MST signals can be useful in collaborative tasks. Researchers developed various prototypes to transmit MST signals, which helps to decrease boredom [65] in tasks, increase users' feeling of friendliness [65], strengthen emotions in life storytelling and collaborative remembering tasks [61], and provide a higher chance of winning the game tasks [9].

Adding MST signals in remote communication positively affects intimate communication. With different prototypes, couples can stay in sync [86], feel closer [14] and more concentrated [14]. MST signals help increase relationship satisfaction [9] and emotional engagement through the physical interaction with the partner [8], [9]. Meanwhile, it decreases perceived stress for long relationship couples [9].

In remote greetings, users prefer experiencing MST signals to mid-air gestures. Zhang et al. [15] designed SansTouch to exchange greetings, and they found that participants prefer using SansTouch over mid-air gestures when exchanging greetings face-to-face with colleagues [15].

MST signals also positively affect other interpersonal communications. Haptic prototypes, such as CheekTouch [10],

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MobiLimb [13], Wrigglo [60], ForcePhone [54], Bendi [59], a mood vector [64], and Shake2Talk [79], could help to persuade [10], communicate emotion [10], [54], [60], [64], communicate information [10], emphasize important information [10], be playful [10], [79], stimulate curiosity and engagement [13], reflect users' presence [54], [60], express greetings [54], experience rich haptic expressions [58], [59], and coordinate events for action, awareness, reassurance, and social touch [79] in mobile communication.

3.4.5 Communication concepts

People have different preferences in communication concepts when they transmit MST signals in mobile communication. For example, Kowalski et al. [62] compared three setups: mobile-only, semi-hybrid (mobile only and mobile + hardware), and hybrid (mobile + hardware). They found that users preferred the hybrid communication concept, as it enhanced their intimate communication by providing emotional closeness [62].

3.4.6 Contexts

Different contexts may cause different perception of haptic stimuli for people. For example, Salminen et al. [49] compared the affective ratings of haptic stimuli in laboratory and bus environments. The results showed that the haptic stimuli were rated as more pleasant, less arousing, and less dominant in the bus compared to the laboratory setting [49]. Similarly, Seebode et al. [82] compared the perceiving of haptic stimuli in a working context versus a leisure time situation. No significant effects were found in the context when rating the affective impression of Tactons designed in [82].

3.4.7 Special users

Haptic devices could help special users, such as deafblind or visually impaired users, to have a better experience in mobile communication. For example, Ranasinghe et al. [78] provided the deafblind people with a haptic device to communicate textual information. The system can translate visual and audio information into haptic stimuli [78]. Similarly, Choi et al. [51] designed image-based tactile emoji, which can improve visual impaired people's texting experience and help them express emotion through tactile imagery. Additionally, Réhman and Liu [77], [87] provided approaches to extracting emotional information and coding and rendering vibrotactile stimuli. The user study indicated touch could enrich the communication on mobile devices and help visually impaired people sense the emotional expressions of other people [77], [87].

4 Discussion

In this part, we discuss the design concerns, the advantages, the disadvantages, possible solutions, implications, and future work for MST on mobile devices from different aspects.

4.1 Design for target users, age groups, and special users

We summarized users' demands from selected papers. We found some guidelines for target users, age groups, and special users.

For target users, the relationship and familiarity between users are very important when developing prototypes for MST signals. For example, some prototypes are designed for couples in a romantic relationship, such as Kissgenger [8], [9]. This prototype may not be effective for strangers or colleagues. Besides, other relationships between users, such as parent–children or grandparent–grandchildren [21], could also be considered.

For age groups, broadening the age group could be future research. Most studies focused on adults aged 18 [47] to 60 [28]. And most participants studied or worked at the university. Those participants covered a large range of active users for the mobile device. However, not too many researchers considered young people under 18 or older adults above 60. They may have other demands when using mobile devices to transmit MST signals.

For special users, paying more attention to them could be a future direction. Several studies focused on people such as visually impaired people [51], [77], [78], [87]. Mobile devices could be essential in their daily lives [104]. Tactile and vibrotactile displays have been used for them to interact with the mobile touchscreen, such as texting [105], and function manipulation like 'zooming of graphical information' [106] or input and scrolling [107]. To further enhance the user experience for special users, researchers could explore a deeper understanding of the difficulties they face, their specific touch requirements, and the social demands in transmitting MST signals through mobile devices [108], [109].

4.2 MST signal design for mobile devices

We summarized the MST types based on selected studies. We found some implications for future design, as follows:

- The context matters when designing MST signals. Some studies have no context in the user study, such as [46] and [47]. There was only a recognition test of social touch. Participants indeed can provide some advice about the MST signals and the communicated emotions. However, some new variables may emerge when adding context to the user studies. The scenarios or the partner's attitude may also affect the perception of haptic stimuli. Thus, adding specific context to the test can improve the research results.
- Designing for the frequently used MST gestures is more efficient. Figure 2.5 shows that some MST gestures are

more popular than others. The reason could be that users may prefer to use those specific MST gestures in remote communication. Similarly, Wei et al. [52] found that users prefer expressing happy or sad expressions over neutral emotions in remote communication. Furthermore, The survey in [21] also showed that users preferred social touch gestures that they wanted to use in remote communication. Thus, frequently used MST gestures are important for future design.

- Creating a social touch set is efficient in design. Many researchers have already chosen different social touch gestures to design with various technologies. But there is not a comprehensive analysis of the social touch set. Future studies could consider generating a social touch set based on a touch dictionary such as [110] to organize the touch design.

4.3 User-centered design methods in MST signals

We found some user-centered design methods in MST signals based on the selected papers that could be interesting for future design, as follows:

- Collect users' social touch properties (e.g., pressure and duration) and design MST signals based on collected data. For example, Park et al. [11] asked participants first to perform social touch (e.g., pat, slap, tickle, and kiss) to find the representative gesture patterns. They design vibrotactile stimuli based on the collected multi-touch input and touch coordinates [11].
- Let users define and create MST signals by themselves and ask them to recognize their design of MST signals. For example, Strohmeier et al. [46] asked participants to express emotions by changing the shapes of a shape-changing interface. They also investigated if other participants could recognize the emotions generated by the shape changes. Similarly, Hannan et al. [47] asked participants to express and recognize the emotional intensities generated by gestures on touchscreens. They found the recognition of emotional intensities was significantly affected by the gesture's size and pressure [47]. Additionally, Shiraga et al. [83] asked participants to generate vibration patterns to express impressions, such as ordinary, uncomfortable, cheerful, etc. They found a relationship between vibration patterns and impressions [83].
- Provide different choices to users and ask them to choose what they want in a specific context. For example, users in [1] preferred using squeezing gestures to communicate unpleasant emotions.

In general, considering users demands in designing MST signals is important in haptic design.

4.4 Generative methods – from HC to HCH

We found two main research fields (HC and HCH) from selected papers. The test in the HC field is usually without real communication. Users interact with the mobile device and perceive the haptic stimuli, which can be assumed to be sent by other people such as the experimenter. In comparison, the test in the HCH field is usually with real communication. Users communicate with each other via mobile devices.

We do not think the two fields are separated. These two fields have both advantages and disadvantages. On the one hand, only considering HC can provide a large set of haptic stimuli quickly, but those haptic stimuli may not all be effective when taking them into the HCH applications. The intended expressions may not be perceived correctly without any context in communication [111], [112]. On the other hand, only considering HCH helps increase design efficiency as researchers can directly integrate the haptic stimuli with the existing mobile applications. However, the problem could be that the number of haptic stimuli may be limited.

Based on the above, we need to confirm whether many or several haptic stimuli are required and choose the generative method that suits us.

We could also consider these two situations together in future design. For example, we can follow two steps in design. Starting from the HC field, researchers could generate a large set of haptic stimuli and have a thorough understanding of the effect of haptic stimuli through a user study. Then, researchers could screen and select the appropriate haptic stimuli and bring them into the HCH study. Researchers then test the effectiveness of selected haptic stimuli under specific contexts during remote communication.

4.5 Applying different types of haptic stimuli for one MST gesture

We found that one MST gesture could be presented by different types of haptic stimuli. For example, the stroking gesture can be achieved by movements [13] and vibrotactile stimuli [5]. Using different haptic stimuli to present MST gesture could present richer effects, but there are more issues to be considered.

One major limitation is the technical constraint. Currently, there is no simple and low-cost mass-produced actuator that can achieve multiple types of haptic stimuli. This means that using different types of haptic stimuli for a single MST gesture would require multiple actuators, which can increase product costs.

The workload on users can increase when there are too many types of haptic stimuli, particularly in remote communication where visual and audio channels are typically main channels. Touch is often considered supplementary in such scenarios [21]. For example, Marc et al. [113] indicate that the visual and haptic channels play dominant roles in different situations.

Therefore, researchers should balance various channels to avoid unnecessary design of stimuli, considering that the visual channel is dominant in sensation within a certain context.

When designing haptic stimuli for mobile devices, a common limitation is that popular devices like smartphones or tablets usually have a single actuator. This makes it difficult to provide different types of haptic stimuli, such as movements and vibrations, simultaneously, as shown in previous studies like [32].

Future research could develop actuators to present different types of haptic stimuli together. But for now, the most efficient way to meet users' needs is to use the actuators that are getting widely used in mobile phones, such as the LRA. And consider visual and audio modalities together with touch to provide rich effects.

4.6 User demands for products and consumer demands in the market

We found developing accessories and connected devices for the mobile device is a popular way to transmit MST signals in current studies. There are many advantages to do this. For example, the accessories of MobiLimb [13] can provide richer touch effects while the SansTouch [15] can provide real touch effects.

However, several issues should be considered: (1) maybe users do not want to buy accessories or connected devices due to the high cost associated with it, as well as an inadequate motivation [114]. (2) Extra maintenance may be unmanageable [115]. (3) Usage frequency may be low since additional effort is required from users, such as remembering to use it and occasionally recharging it [114]. Thus, if researchers want to develop accessories and connected devices, they should consider factors from design and market aspects together.

From the design aspect, researchers should consider target users, user demands, and contexts. Or the device may not be helpful. For example, in [32], many participants found using emojis on the phone easier and more efficient to express their emotional states than the connected device – EMO. Also, some participants thought the prototype was for children since it looked like a toy [32]. Thus, the shape, the interaction, the target group, and the context are all important when designing accessories and connected devices.

From the market aspect, consumers may have more considerations in the purchase. We take the wearable as an example. Jung et al. [116] show that besides the display shape, size, and standalone communication, brand and price are also important factors that need to be considered for wearables such as smartwatches. Yang et al. [117] show that besides the perceived usefulness and enjoyment, social image is also important in customers' perceived value of wearable devices.

In general, to develop accessories and connected devices for transmitting MST signals, considering both the user demands from the design aspect and the consumer demands from the market aspect is important.

4.7 New forms of MST signals

Most studies provided MST signals through haptic stimuli by actuators such as motors. We still found some new forms of MST signals, as follows:

- *Applying new material*. Teyssier et al. [118] developed an artificial skin as a skin-on interface. They conducted three user studies to choose a better material to reproduce the look and feel of the human skin [118]. Meanwhile, Weigel et al. [119] explored how the gestures input on the skin could be transformed on this new interface. This skin-on interface can be used as a phone cover, a smartwatch cover, or a touchpad with artificial skin, which is a possible way to transmit real social touch on a mobile device [119].
- *Applying flexible surfaces*. Mobile devices usually have a rigid screen. The shape-changing of screens could present effects that hard screens cannot achieve. Although we do not have a mass-produced flexible screen for mobile devices at present, some researchers have already tried to explore the possibility of using it. For example, Bendi [59] is a phone-sized and phone-shaped prototype that can provide shape-changing movement during a phone call. Lahey et al. [120] provided PaperPhone and evaluated the effectiveness of bend gestures in conducting tasks with a flexible display. Strohmeier et al. [46] created a 2D flexible surface and explored the possibility of conveying emotions through this new flexible surface. The sensor's dimensionality and 2D form factor have the potential to be developed as a circuit sandwiched behind a flexible display, which makes it possible to make the flexible display in a flexible smartphone in the future [46].

Based on the above, technology is a significant barrier to new forms of MST signals. But researchers can still simulate new forms with some simplified prototypes and explore the potential of MST signals.

4.8 Design for new mobile application

Adding MST signals to traditional mobile communication, such as texting [63] and voice calling [10], [11], [14], was common in haptic design. However, the newly developed smart mobile devices provide more possibilities in haptic design for mobile communication. We need to consider the new mobile applications when designing MST signals, as follows:

- Considering the change in the use of mobile devices in mobile communication. For example, users usually put their mobile phones on their ears during a phone call in the past. So, POKE [14] and CheekTouch [10], [11] focused on presenting haptic stimuli on users' faces and cheeks during a phone call. Nowadays, smartphones are more and more popular. Headphones are easy to connect with the smartphone, so users do not need to put the phone on their ear during a phone call. New forms of MST signals during a phone call need to be explored.

- Generating MST signals for video calls could be a popular trend because, with the development of smartphones, video calls are becoming popular on mobile devices. Rognon et al. [21] found that users prefer to use MST gestures during a video call. Many researchers have already tried to develop MST signals for video calls [5], [9], [13], [53], and [64].
- Developing haptic stimuli for existing icons conveying emotion is also popular. Online chatting applications, such as WhatsApp and WeChat, can present emojis and stickers. Many researchers have studied haptic stimuli for these emojis and stickers [34], [68], [70], [71], [75].

In general, new forms of MST signals are based on the latest mobile technology and applications. Future designs about MST signals for mobile communication could consider new mobile applications (e.g., TikTok and mobile augmented games) and technologies (e.g., new actuators, virtual reality displays, and metaverse).

5 Limitations

There are some limitations to this paper. Firstly, we excluded prototypes with wearables that did not provide haptic stimuli on users' hands, but some of these studies are valuable for future remote communication on mobile devices. For example, Wang et al. [42], [43] created a phone cover for people to squeeze, transmitting the squeezing pressure to an armband. The phone cover is a possible and acceptable way for users as many people like using a phone cover to decorate or protect smartphones. Israr et al. [34] and Graham et al. [33] provided haptic stimuli to users' wrists with smartwatches. Smartwatches are also widely used by many people, which can be a potential research direction when designing MST signals.

We excluded studies without complete user studies on social touch, but some concepts have a good potential for future application. For example, Hemmert et al. [121] created three concepts of transmitting grasping, kissing and whispering on the mobile device. Teyssier et al. [118] experimented with a skin-on interface to send social touch or other notice on the mobile device, smartwatches, and touchpads.

We only considered research articles in four main digital libraries (ACM digital library, IEEE Explore, Springer, and Scopus) in English. However, some short articles, posters, or exhibitions may not achieve a full research level at present, but the new concepts they bring are valuable for future design and research. Other digital libraries, languages, and literature types other than research articles could also be considered.

6 Conclusions

This paper presents an overview of MST designs and evaluations on mobile devices based on selected 52 articles.

From the perspective of MST design, we summarized the following:

- *Typical haptic input*. There are two typical haptic input types: pre-defined signals and real-time generated signals. There are four types of real-time generated signals (i.e., touch gestures, shape change, joystick, and GUI.
- *Typical haptic output based on different actuators and parameters*. There are four types (i.e., shape change, pressure, vibration, and other tangible output).
- *Mediated social touch*. There are two types – specific and non-specific.
- *Emotion that social touch communicates*. There are two types: specific emotion and emotion dimensions.

We also find that actuators, accessories, and connected devices are currently three typical prototypes researchers developed for MST gestures and signals.

We summarize the evaluation of MST research from the perspectives of participants, experiment design, and data collection. We have learned what conclusions benefit future research, especially in the aspects of signal design, multimodal stimuli, gesture evaluation, MST signals in the application, communication concepts, contexts, and special users.

We also discuss possible solutions for the found issues and suggest directions for future MST design and research. The main issues that designers and researchers could consider in future design are: (1) consider target users, age groups, and special users; (2) Design frequently used MST signals for specific context; (3) Apply user-centered design methods and choose an efficient generative method; (4) Consider the user demands of products and consumer demands in the market together in the development; (5) Consider new forms of MST signals; (6) Design for new mobile applications and technologies.

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