Virtual Reality (2006) 9: 149–159
DOI 10.1007/s10055-005-0014-2

ORIGINAL ARTICLE

Antal Haans · Wijnand IJsselsteijn

Mediated social touch: a review of current research and future directions

Received: 29 July 2005 / Accepted: 7 October 2005 / Published online: 10 December 2005
© Springer-Verlag London Limited 2005

Abstract In this paper, we review research and applications in the area of mediated or remote social touch. Whereas current communication media rely predominately on vision and hearing, mediated social touch allows people to touch each other over a distance by means of haptic feedback technology. Overall, the reviewed applications have interesting potential, such as the communication of simple ideas (e.g., through Hapticons), establishing a feeling of connectedness between distant lovers, or the recovery from stress. However, the beneficial effects of mediated social touch are usually only assumed and have not yet been submitted to empirical scrutiny. Based on social psychological literature on touch, communication, and the effects of media, we assess the current research and design efforts and propose future directions for the field of mediated social touch.

Keywords Physical contact · Social touch · Interpersonal interaction · Literature review · Computer mediated communication · Haptic feedback

1 Introduction

Humans use their sense of touch to physically interact with the world and others around them. The sense of touch provides us with useful information on the position and movement of our body limbs in time and space, and on the shape, size, weight, and texture of external objects, and enables us to use tools such as a hammer, a pen, or a personal computer. From a developmental psychological perspective, touch plays an essential role in our perceptual construction of spatial environmental layout. Combining touch and vision allows the simultaneous extraction of perceptive invariants, a process crucial for establishing the reciprocal connections that allow for higher order perception and categorization of objects and environments. By its very nature, physical interaction, in comparison to visual, auditory, or olfactory interaction, *always* occurs within one's peripersonal space; i.e., the space in which one can touch and manipulate objects, and is within reach of, perhaps dangerous, objects (e.g., collision) and other people (see Ref. [1]).[1]

Touch is particularly significant in social interactions. A short touch by another person can elicit strong emotional experiences; from the comforting experience of being touched by one's spouse, to the experience of anxiety when touched by a stranger. Indeed, human touch bears the capacity for very personal and very intimate interpersonal interaction, and can potentially evoke a sense of "proximity and establish the human connection" ([2], p. 88). Not surprisingly, people use touch when providing encouragements or emotional support, or when expressing intimacy or tenderness (see e.g., [3, 4]). By contrast, touch can also be a powerful means to gain compliance, or to persuade someone (i.e., the Midas touch; [5]).

Although various technologies for mediated physical contact exist and are used in human-computer interaction, teleoperation systems, and sensory substitution systems, current communication devices still predominantly rely on the senses of vision and hearing. However, in recent years, there has been an increasing interest in mediated touch for interpersonal interaction, resulting in a considerable amount of studies and prototypes. By

This research was supported by the JF Schouten School for User-System Interaction Research at Eindhoven University of Technology, Eindhoven, The Netherlands

A. Haans (✉) · W. IJsselsteijn
Human Technology Interaction Group,
Eindhoven University of Technology, IPO 1.26,
P.O. Box 513, 5600 MB Eindhoven, The Netherlands
E-mail: A.Haans@tm.tue.nl
Tel.: +31-40-2475237
Fax: +31-40-2449875

[1]There is one cutaneous submodality that can be perceived from outside the peripersonal space (i.e., without direct contact with the body), namely warmth (see [1]).

adopting the metaphor of remote or mediated social touch (cf., [6]), we review and assess this research and design work to date and provide suggestions for future directions of research in this area.

2 The physiology of touch

The human touch sense is one of the five classic senses or modalities, the others being vision, hearing, smell, and taste. Through our sense of touch we are capable of detecting different types of stimuli (i.e., sub-modalities), such as pressure, vibration, pain, temperature, and position. In fact, the human sense of touch can be divided in two sub-systems: The *cutaneous system* (also called the *tactile system*) and the *kinesthetic system*. *Haptic perception* (also called *tactual perception*), then, refers to situations where there is both tactile and kinesthetic perception [7–9].[2]

The cutaneous system refers to the different receptors in the skin (i.e., nerve endings) and their receptive afferents (i.e., nerves conveying sensory information from the receptors to the central nervous system). The skin contains different types of receptors each with more or less specific sensitivity to a certain sub-modality. Temperature is sensed by the *thermoreceptors*. The sensation of pain is attributed to the *nociceptors*. Deformation or physical displacement of the skin (e.g., by vibration, pressure or stretching) is sensed by the *mechanoreceptors*. A further discussion of the characteristics of these different types of cutaneous receptors is beyond the scope of this article (for reviews, see e.g., [10–12]).

The kinesthetic system is responsible for one's awareness of the movement and position of one's limbs in time and space. Accordingly, kinesthetic perception also contributes in determining the size and weight of objects. Although visual information also contributes to the awareness of limb position, the kinesthetic system refers to the information received from the receptors in the limbs themselves (i.e., *afferent* information)[3]. For a review on the receptors of the kinesthetic system, see Ref. [13]. Next to the afferent information people receive from the receptors in their limbs, information from the brain's own motor-commands (i.e., the *efference copy* or *corollary discharge*) plays a role in haptic perception as well. Weber [14] was probably the first to mention that the active exploration of objects with the hands significantly improves touch perception.

[2]We prefer to use the term kinesthesia instead of proprioception, as the latter is ill-defined (see [13]). Following Sherrington [121], who coined the term, proprioception is the sense of body position and movement and includes sensations from the muscle and joint receptors (i.e., the kinesthetic system) as well as from the semicircular canals and otolith organs (i.e., the vestibular system).

[3]Cutaneous perception, especially through the stretching of the skin, might play a role in the sensation of body limb movement and position as well (see [13]).

3 The technology of mediated touch and its applications

Mediated touch allows people to use their sense of touch in interaction with and through computers. The strength of the technology for mediated touch is that it is dynamic. In comparison to static technology, such as the embossed dots of the Braille language or the raised line drawings for people with a visual impairment, *dynamic* systems continuously adjust themselves to the changing information in the environment and the actions of the user [15]. Hence, the technology for mediated touch is generally referred to as haptic feedback. Generally, two types of haptic feedback technologies can be distinguished: tactile and kinesthetic (or force) feedback [16].

Tactile feedback provides dynamic stimulation of the cutaneous receptors (for a review of tactile displays see e.g., [17, 18]). Electrotactile actuators, either a single one or placed in an array, work by passing an electric current through the skin. As the human skin does not contain specific receptors for electrotactile stimuli [12], electrotactile actuators provide sensations ranging from wetness, vibration, an itch, a tingle, or even pain [18, 19].

Deformation or displacement of the skin can be achieved by a single or an array of mechanical or vibrotactile actuators, which can be placed on the body or can be used in active exploration (i.e., active haptic perception; as in, for instance, raised line drawings). *Mechanical actuators* are small non-vibrating elements that press on the skin and can be dynamically controlled by for example shape memory metals or hydraulics. The most frequently used *vibrotactile actuators* are electric vibration motors comparable to the ones used in pagers or cell phones (for technical descriptions of both mechanical and vibrotactile actuators, see Ref. [16]). Less commonly used are *temperature actuators* such as Peltier elements (see e.g., [20–22]).

Kinesthetic feedback primarily aims to stimulate the kinesthetic receptors in a user's limbs by applying force to the limbs themselves. Actuators are either incorporated in exoskeletons (e.g., Rutger-Master II; [23]), in table-based systems, such as the PHANToM [24], which is the most frequently used haptic interface today, or in force feedback arms, such as the HapticMaster [25], which allows for a larger spatial interaction range and higher resistive (or assistive) forces.

The effectiveness of haptic feedback may benefit substantially from appropriate visual stimulation. In support of this contention, there have been a number of recent reports on visually induced haptic illusions. For instance, Biocca, Kim, and Choi [26] report on an experiment where participants interact with a virtual spring and report a haptic sensation of physical resistance, even though no haptic feedback was present. Further research is required to exactly quantify this perceptual illusion and establish its boundary conditions, but it is clear that this kind of crossmodal transfer will be relevant to the design of haptic interfaces (see e.g., [27]).

3.1 Human-system interaction and virtual reality

For human-system interaction, haptic feedback can improve traditional graphical user interfaces. Already in the 1960's, Geldard [28, 29] described several ways to create a language on the basis of *vibrotactile* stimuli, and currently, the communication of simple ideas by means of vibrotactile stimuli, again, receives considerable attention (e.g., vibrotactile icons; e.g., [30–33]). Tactile icons can, for example, be used to reduce sensory overload [34], or to reduce the social weight of interacting with mobile devices (i.e., to relieve some of the stress that operating a device has on ongoing social interactions; [35]). Another promising application of tactile feedback is to provide users (e.g., astronauts, see Ref. [36]) with directional information (see also Ref. [37]). *Kinesthetic feedback* was first used for teleoperation (e.g., the manipulation of a robot over a distance; for a historical overview, see Ref. [38]). Haptic feedback makes teleoperation more effective, because users can now both feel and see what they are doing as if they were at the remote site. This experience is called telepresence or distal-attribution (see e.g., [39, 40]). In the recent decades a new dimension has been added to human-system interaction, namely that of virtual reality [16].

Virtual reality systems (VRs) benefit significantly from the inclusion of haptic feedback [15] and haptic feedback is a necessity when VR is used for training applications (e.g., for surgery; see e.g., [41]). Haptic feedback has also been shown to be effective in VR therapy (e.g., in the treatment of spider phobia, [42]). When combined with haptic feedback, traditional audio-visual virtual environments (e.g., head-mounted displays) become more immersive [43]. That is, haptic feedback can potentially increase a user's sense of presence (i.e., his or her experience of being in the virtual space, see Ref. [44]). Especially the active manipulation of virtual objects (i.e., active haptic perception) is important in creating a sense of presence, as it is argued that the effect of interactivity on presence depends on the degree of motor-sensory contingencies (e.g., [45, 46]). An interesting new and technologically challenging application of haptic feedback can be found in co-operative virtual environments. Using a ring on a wire game, in which two distant users jointly maneuvered the ring, Basdogan, Ho, Srinivasan, and Slater [47] showed that kinesthetic feedback significantly increased users' performance level and sense of togetherness. Although more research is required to validate this finding, the authors also report that as a result of kinesthetic feedback users were more accurate in guessing the gender of the interaction partner. In a different study [48], users had to jointly grasp and stack a series of virtual cubes. This study again showed significant positive effects of kinesthetic feedback on task-performance and the experience of presence.

As we mentioned briefly in our introduction, the significance of touch is not limited to exploring objects and environments, but clearly plays an important role in social interactions as well (cf., [6, 49]). In the remainder of this paper we will concentrate on this aspect of mediated touch. In order to do this, we will first review a number of basic social psychological effects of touch, and will then turn to existing prototypes that are aimed to transmit touch for interpersonal interaction and communication.

4 The psychology of social touch

For the purpose of this review, we define unmediated interpersonal interaction as all those instances in which people are in each other's presence and have a reciprocal influence on each other's actions, whatever this influence entails (see Ref. [50]). In this review we are mainly concerned with the type of physical interpersonal interaction that is called social touch. *Social touch* entails all those instances in which people touch each other, for example in a crowded train, when shaking hands, or when giving a "simple" touch of appreciation. Obviously, people need to be in each others immediate proximity (e.g., as in face-to-face interaction) to touch.

Social touch, or the lack of it, has profound psychological effects on human beings in all stages of their lives. According to some authors (e.g., [51]) social touch is a fundamental human need, to others (e.g., [3]) it at least has *intrinsic functions*. Newly born, for example, require occasional physical contact to ensure good physical and social development (for an overview, [52, 53]). When the child matures, a *communicative function* of touch will become important as well, when through social interaction physical contact acquires a *common* or *shared symbolic meaning* [3, 51].

4.1 Touch as nonverbal communication

Human communication essentially consists of a series of goal-directed acts, in which a person (i.e., the sender) makes an indication to an other person (i.e., the receiver) to evoke the intended response, whether the adoption of an idea or a change in behavior or attitude, within that person [54]. For communication to be effective the meaning of what is indicated by the sender (i.e., the message) should be adequately interpreted by the receiver. Therefore communication, as a special case of interpersonal interaction, requires that at least part of the message should have a *common* or *shared symbolic meaning* (i.e., should consist of significant symbols, [54–56]). This implies that the intentionality of the message should be commonly agreed upon as well (see also Ref. [57])[4]. The social meaning model of touch assumes that many forms of physical contact have acquired a

[4]Note that this contradicts the popular statement that "one cannot not communicate" ([122], p. 49); the logical derivative of the view that all interpersonal interaction is communicative (for a further discussion see e.g., [56]).

culturally shared symbolic meaning [58, 59]. In other words, many types of touch are *significant symbols*, meaning that they represent similar ideas and evoke similar responses in the persons who initiate the touch as in the persons who receive the touch [54, 55]. When a particular touch has become a significant symbol within a social group, then members of the group have *general expectancies* about the usage of this touch by other members (i.e., there is a *social norm*), and as a result that touch can be safely used in communication amongst members of the group [59–61]. Since the interpretation of meaning depends on the context and the complete message in which the touch is embedded, there may exist multiple common symbolic meanings to a particular type of physical contact. According to Burgoon and Newton [58] there is a social meaning when the range of possible interpretations is restricted.

4.2 Symbolic meanings of touch

Remarkably, few studies have actually investigated the meanings people assign to being touched. Even more remarkably, those that do, mostly rely on people's responses to *pictures* or *movies* in which people are touched and not on responses of people that are touched themselves (cf., [62]). One exception is the study of Jones and Yarbrough [3], who, by using a diary study, identified six different categories of meaning: positive affection, control, playful, ritualistic, task-related, and accidental touches. *Accidental touches* (i.e., perceived as occurring in- or accidentally) although perhaps informative, are not interpreted as symbolic (i.e., as a communicative signal). *Task-related touches* are also not interpreted as symbolic, as their meaning is inherent to the action itself. Examples of task-related touches are helping someone out of a car or brushing dust from someone's face. Of all communicative touches, *positive affection* is regarded to be the most important category. Jones and Yarbrough describe different types of affectionate touches, such as to give support (e.g., "let me take care of you") or to show appreciation (e.g., "I really value what you did"). Most touches in this category, however, primarily indicate affection (e.g., "I like you"). This last type of affectionate touches strongly signal intimacy (cf. [4]). Although they do exist, touches with a negative affective meaning were not encountered in the study of Jones and Yarbrough. Whereas affective touches communicate one's emotional state or empathy to the other person, *control touches* are primarily used to change the behavior, attitude or emotional state of the other. Two often encountered types in this category are touches to obtain compliance or attention from the other. Another type of control touch is associated with dominance or status (see Ref. [63]) *Ritualistic touches* basically do not have a personal meaning, but instead are used to regulate interpersonal interactions. They include greeting and departure touches, such as a handshake, which often indicate the transition from unfocused to focused interactions (i.e., act as an agreement to enroll in face-to-face communication; see Ref. [64]). Ritualistic touches are often extended to include affective meanings as well. Finally, *playful touches* have a meaning that is different from what would be expected from the touch itself, but instead meaning is inferred more from situational and other, often verbal, cues. For example, saying "you have something on your nose", brushing it off (i.e., in itself a task-related touch), and then saying "just kidding" has in essence an intimate meaning.

4.3 Effects of touch on social interactions

Touching inevitably affects interpersonal interactions. In fact, research has shown that when touched briefly and discretely, people displayed increased *self-disclosure* (e.g., [65]), increased *positive gratitude* (i.e., a positive evaluation of the person who initiated the touch; e.g., [59, 60, 66–68]) and increased *compliance to a request* (e.g., [67–71]). Compliance to a request manifests itself even when the request is not made directly (i.e., increased *pro-social behavior*; e.g., [72–74]), and when participants are not aware of being touched [75]. More specifically, a person's participation in a course increased when he or she was touched by a teacher [76], and when touched by a waitress, it increased a person's tipping behavior (i.e., the Midas touch; [5, 77]), and alcohol consumption [78].

5 Mediated social touch

In Sect. 4, we defined unmediated interpersonal interaction as all those instances in which people are in each other's presence and thus have a reciprocal influence on each other [50]. However, an increasing proportion of our daily social interactions is mediated, such as through written mail, traffic signs, or telephone, and enables us to have an influence over an other person's actions even when physically and temporally separated. Depending on the technology used, technology-mediated interaction differs from non-mediated interaction in several ways [79]. Mediated interaction often supports fewer channels (e.g., text or audio only), and as a result often lacks the capability to exchange contextual and nonverbal cues. Moreover, mediated interaction can occur asynchronously (i.e., with a delay between sending, receiving and responding), and messages can sometimes be reviewed and revised. As a result of these differences, various forms of mediated interaction have their own specific strengths and weaknesses, depending on the specific communication need and task. *Media richness* (i.e., the extent to which a communication medium facilitates immediate feedback, multiple channels, and contextual and nonverbal cues) aims to explain the effectiveness and efficiency of media for different tasks [80]. Compared to a face-to-face conversation, media low in richness are for example less suitable when discussion, clarification or decision making is required, but more suitable when the meaning of what is indicated is already agreed upon or enforced (e.g., traffic signs). Second, mediation inevitably affects a user's perception of his or her interaction partner and of the interaction with that person. Media, especially those low in richness, often fail to provide users a sense of *social presence* (i.e., the experience of being together; [44, 81, 82]). As a result, some of the reciprocal influences that are tantamount to and guide interpersonal interactions in non-mediated situations, such as social facilitation and inhibition, are less prevalent in mediated interactions (cf., [83]). Since these influences largely depend on a common symbolic meaning system, some authors (e.g., [84]) have argued to replace social presence by *social verification*; i.e., the extent to which people find themselves interacting on the basis of significant symbols.

We define mediated social touch as the ability of one actor to touch another actor over a distance by means of tactile or kinesthetic feedback technology. Several benefits of mediated social touch are mentioned in the literature. First, the addition of a tactile or haptic channel to communication devices can enhance or enrich mediated communication (e.g., [85–91]). However, why and in what ways communication is enhanced or enriched often remains unspecified. For some authors (e.g., [86, 87]) communication is enriched, when adding the touch channel will increase the amount of information that can be transferred (i.e., is not redundant). Other authors (e.g., [89, 92]) mention that the touch channel can compensate for the loss of nonverbal cues that results from the use of current communication media.

Second, since touch is indispensably related to intimacy, mediated social touch allows for personal and intimate interactions in ways that words or images presumably cannot (e.g., [6, 85, 89, 90, 93–95]).

The third and final benefit of mediated physical interpersonal interaction is that the sense of touch is very suitable to substitute the other senses in situations where other types of interpersonal interactions are impossible to use (e.g., in a library), where there are privacy demands (e.g., when very personal information is exchanged in public; see Ref. [86]), or where there is the danger of cognitive overload (e.g., when interacting while performing other tasks; [90]).

5.1 Current prototypes and user tests[5]

The idea of using the sense of touch for mediated interpersonal interaction is not new (see Sect. 3). However, instigated by developments in ubiquitous computing and tangible interfaces (see e.g., [96, 97]), there is a renewed interest in mediated social touch for the non-sensory-impaired. Current prototypes are the result of diverse design philosophies that do not lend themselves easily for classification. Despite their differences, the devices discussed in this section have in common that they all support interpersonal interaction in ways that exceed purely task-related or practical communication [98]. Instead, many of these prototypes aim to provide people with a sense of presence of a distant other (comparable to awareness systems, e.g., [99]), or a sense of connectedness [100].

One of the earliest designs is the *electronic arm wrestling system* by White and Back, which was demonstrated at the Strategic Arts Initiative Symposium, in Salerno, Italy, 1986. By connecting two robot arms over a conventional telephone line the system enabled two persons to arm-wrestle over a distance. Although time delays prevented a real wrestle, it was said to be sensitive enough to give the impression of wrestling a real human [101].

Another device for interpersonal entertainment is the *HandJive* [102]. Fitting in one hand, the HandJive consists of two balls that can be placed in different discrete positions. Whereas a symmetric mapping (e.g., see Ref. [87]) between both users was a requirement for the telephonic arm wrestling system (i.e., the robotic arm needed to be both an input as well as an output channel to enable wrestling), Fogg et al. opted for an indirect interaction (i.e., asymmetric) to reduce fighting for control. A user can move the balls on his HandJive in one orthogonal field (e.g., the up and down channel), whereas the position in the other orthogonal field (e.g., the left to right channel) is the result of the other user's action on his or her HandJive. Although originally designed for interpersonal entertainment the authors explored the use of the HandJive for communication, and describe Tactilese, a haptic language based on patterns of ball positions.

The *Intouch* system [85] consists of two connected devices each with three independently rotationable rollers. A symmetrical mapping between the two devices creates the illusion of handling a shared object and enables physical interpersonal interaction and communication. The connection between the two devices could be similar to that used in teleoperation, but the initial prototype had a mechanical connection through drive-shafts. No formal user tests were conducted, but initial trials indicated that the interaction was playful, but ambiguous in meaning.

Chang et al. [86] envisioned the *ComTouch*, a device that is fitted over a traditional mobile phone and translates finger pressure into vibrotactile stimuli. A first prototype that was built only allowed for one finger to be used. With the tip of the finger pressure could be applied to a force sensing resistor (FSR) and the resulting signal was presented to the middle part of the sender's finger to give feedback about the frequency and amplitude of the generated signal. The base of the finger was used to receive signals from the other user. In an experiment they found different uses of the tactile

[5] For a different overview of prototypes that enable mediated social touch, see van Essen and Rovers [91; also Rovers & van Essen, this issue].

channel: emphasis, turn-taking, mimicry, and in a touch-only scenario also encoding of specific meaning.

According to Dobson, Boyd, Ju, et al. [103] the tactile channel is perhaps more suitable for the exchange of emotional states or moods, than for the exchange of complex information or specific meanings. Dobson and colleagues describe the *VibroBod*, a rubber object that, while resting on a person's lap, is held with both hands and can be used during a telephone communication or instant messaging. Containing FSRs, microphones and vibrotactile actuators, the VibroBod captures a user's force of grip, which, combined with his or her vocal inputs, is mapped to specific vibration frequencies and patterns in the other user's VibroBod. A first user test on a single VibroBod (i.e., with the input mapped to the output of the same device) showed that people were interested in finding out how to generate meaningful representations of their emotional states.

Hansson and Skog [104] envision another device that enables the communication of emotional states: the *LoveBomb*. The conceptual idea behind the LoveBomb is that it enables people to emotionally express themselves in public and among strangers. With the LoveBomb a person can anonymously exchange two pre-defined emotional states, namely love (or happiness), and sadness, to all other LoveBomb users in his or her vicinity. Different vibrotactile stimuli are used to represent love (i.e., representing the pulse of a heartbeat) and sadness (i.e., irregular vibrations).

Oakley and O'Modhrain [105] developed the Contact IM which aims at enriching current instant messaging systems by allowing users to sent each other a haptic instant message. In the Contact IM system the available haptic message consists of the passing of a ball between two users. The action of throwing a virtual ball allows the sender to be expressive, as the momentum of the ball, and thus the corresponding physical sensation of catching the ball, can be freely varied. The haptic feedback of catching the ball can be displayed through for example a PHANToM or more basic force feedback joysticks. To our knowledge, no formal user tests were conducted with the Contact IM system to date.

Another application of haptic communication based on an instant messaging system is developed by Rovers and van Essen [89]. The authors describe the *Haptic Instant Messaging* (HIM) framework. The HIM is basically a standard instant messaging system to which different types of haptic or tactile feedback devices, whether commercially available or custom made, can be connected. Currently only asymmetric bidirectional interaction is provided through so called *Hapticons*, or haptic emoticons. These haptic emoticons are pre-defined haptic or tactile stimuli that represent simple ideas similar to visual emoticons (i.e., smileys; [88], cf., [30, 32]). Users can easily design and modify Hapticons using the *Hapticon Design Tool* (cf., the Hapticon Editor by Enriquez and MacLean, [31]). A possible output device to be connected to the HIM is the *FootIO* ([90], also Rovers and van Essen, this issue). The authors state that although hands are most often used for haptic or tactile communication, the foot may be suitable as well. Reasons for engaging feet in haptic communication are that touching another person's feet is regarded to be highly intimate behavior, the foot is well suited to perceive tactile stimuli, is a suitable body location for concealed communication, and can be used in situations in which the hands are needed for other tasks. With the FootIO, pre-defined Hapticons can be delivered to the foot through an array of eight vibrotactile actuators. First user tests showed that, although they had difficulties in accurately identifying the location and pattern of stimuli with the current prototype, users generally reported that they enjoyed using the device in the context of interactions over the HIM. Whereas some indicated that they used the Hapticons to emphasize text messages, others indicated that a lack of common meaning made this somewhat troublesome.

Other prototypes aim to provide geographically separated people a sense of awareness or connectedness towards each other. Examples of functional prototypes include the *White Stone* [98] and the *Shaker* ([106], also [99]). Compared to the LoveBomb, these devices are privately linked to just one other device. Whereas the White Stones become warm when both users have their device in their hands, when a person uses his or her Shaker, the corresponding device of the other will start to shake in the same manner.

The *PillO'Mate* [107] was designed according a somewhat different design philosophy as the authors do not only emphasize the communicative or symbolic functions of social touch, but its intrinsic functions (e.g., relaxing or recovering from stress) as well. The PillO'-Mate is a cushion that activates itself when its proximity-sensor detects something nearing it. When touched it responds with sound, heat and vibrations. Preliminary user tests focused on the experiential qualities of the shape and texture of the pillow. Based on a similar design philosophy as the PillO'Mate, DiSalvo, et al. [93] and Gemperle, et al. [94] envision the *Hug*. These yet to be developed devices can be connected to each other over a mobile phone network. The authors envision asymmetrical bidirectional physical interaction by which a person can stroke or squeeze his or her device, which will result in vibrations and temperature changes in the other person's device. The authors also envision the possibility to store a spoken message and the vibration and heating pattern when a connection with the other person's hug cannot be established. Whereas the Hug's output is envisioned as vibration and heating patterns, Mueller, et al. [95] aim to provide the receiver with a sensation that according to the authors is perhaps resembled most by an actual hug. This was done by means of an inflatable vest. To initiate the hug another user must stroke the touch screen on his or her koala-bear-like input device. The two systems can be connected through either TCP/IP or Bluetooth. First user tests showed that couples missed the reciprocity of an unmediated hug and found it difficult to envision themselves using it in real life.

As discussed in Sect. 3.1, haptic interpersonal interaction in *cooperative virtual environments* or *shared virtual editors* is especially significant, yet technologically challenging. Alhalabi and Horiguchi [108] describe the *Tele-Handshake*, a kinesthetic feedback virtual environment, which enables people to touch and shake hands over a common network by means of PHANToMs. First tests on the system show that forces could be accurately transferred between users. Participants reported a high consistency between visual and kinesthetic sensation, but found the handshake only moderately convincing. Brave, et al. [6] investigated the effects of mediated social touch on feelings of power and liking of the other person in both a co-operative (i.e., helping another person through a maze) and competitive task (i.e., hindering another user's progress through the maze). Oakley, Brewster and Gray [109] describe five different types of physical interactions that could aid communication between users in a shared virtual editor. These types of interaction include, for example, pushing each other's pointers around, or grabbing and moving another user's pointer. A first experiment on these interaction types shows that although participants reported to have difficulty in using the interface and in communicating with their pointers, they overall reported a higher sense of presence and engagement in the interaction [110].

6 Discussion and future directions

In this paper we have attempted to give a broad outline of the field of mediated social touch, including relevant perceptual mechanisms, enabling technologies, theoretical underpinnings, and current design solutions. Fuelled by improvements in enabling technologies, as well as trends in social awareness systems (e.g., [99]), multimodal interfaces, and tangible computing [96], this field has rapidly expanded over recent years. The prototypes and design ideas reviewed in the present paper have set the stage for future studies on mediated social touch by inspiring researchers and designers, and by providing descriptions of hands-on user experiences with these systems.

However, we feel that in emphasizing design explorations and point solutions, the field has been lagging behind in developing a deeper theoretical understanding of the presumed effects of mediated social touch on the social interaction process. Such an understanding could potentially provide structure to the design space of social touch systems, and may guide the empirical experimentation process, as well as the interpretation of observed effects (or the lack thereof). To date, very few studies are available that report on empirical system validations beyond the level of anecdotal descriptions of user experiences. For the present review, we felt it was not prudent to engage in formulating design guidelines for haptic or tactile communication devices based on the scarce empirical data available in published research. What the relatively new field of mediated social touch would benefit most from at this early stage is more rigorous studies that will put the assumptions that we have encountered in the reviewed literature to the test.

As noted in Sect. 5, most authors do not state exactly how the addition of touch channel will enrich current communication media. According to Chang et al. [86, 87] interaction is enriched when adding the touch channel increases the amount of information that is transferred. However, as was discussed in Sect. 4.1, human communication requires that information is transferred intentionally and in terms of common meaning. Although approaches such as media richness might lead us to conclude that adding more channels will always and automatically enrich communication, this is not necessarily the case. From the preliminary user reports discussed in Sect. 5 (e.g., [85, 90]) we learn that a lack of common meaning is often troublesome and results in ambiguity about how to use a device. For mediated social touch to enrich current communication devices, it should at least satisfy the *prerequisite of a common symbolic meaning* (cf., [111]). We agree with Rovers and van Essen [90] who state that the design of easily understandable haptic symbols (e.g., hapticons or a 'tactilese' language) is a difficult process that requires far more research. Currently, several research teams are exploring how to design tactile icons (e.g., [32, 33, 111]) and first tests on the effectiveness of tactile icons (e.g., [92, 112]) show promising results.

In this paper, we classified the reviewed applications, research and prototypes under the single heading of remote or mediated social touch. Even though current feedback technology does not yet allow for the same physical sensation as a real touch, Brave et al. [6] state that unmediated social touch offers a good framework for exploring the application of mediated touch in communication devices. However, simply assuming that mediated physical interaction is equivalent to mediated social touch can also be misleading, especially when it is used to explain observations (see e.g., [110]). Although most authors of the reviewed articles do not explicitly use the social touch metaphor, the relationship between haptic feedback for interpersonal interaction and its unmediated counterpart, social touch, is often implicitly assumed, and can be inferred from references to the symbolic and intrinsic functions of social touch as well as the supposed intimate nature of addressing the skin as a communication channel (see e.g., [95]). Thus, empirical evidence is required to assess the validity of the mediated social touch metaphor. Although it is certainly true that a touch by another person can elicit strong affective experiences, currently there is no empirical evidence that this is also the case for mediated touch. At the moment, we can only speculate about whether a tactile icon is more personal and intimate than a visual icon, or how it would compare in nature and strength to unmediated touch.

Based on the review of unmediated social touch, interesting research questions present themselves. For instance, will the effects of social touch on interpersonal interactions (e.g., the Midas touch, see Sect. 4.3) also be found in mediated situations? A particularly interesting question is whether people hold the same expectancies (i.e., social norms) about the use of mediated touch as about unmediated touch. In our own labs, for example, we investigated whether the gender differences generally found in same- and opposite-sex touch (e.g., [113, 114]) are also present in mediated situations, using a tactile vest containing an array of vibrotactile actuators. Our preliminary results indicate that, as expected, male participants who were part of a same-sex dyad (i.e., who were 'touched' by a male stranger) experienced the mediated touches as less pleasant than the male participants who were part of an opposite-sex dyad (i.e., who were 'touched' by a female stranger). Through demonstrating such response similarity, that is, replicating in a mediated situation the patterns of (social) responses found in unmediated situations, we provide evidence that mediated touch is perceived in similar ways to unmediated touch. This is a non-trivial finding when one appreciates the significant differences in stimulation between a human touch and a vibrating electromechanical actuator.

If the mediated social touch metaphor proves to be valid, *and this is still highly speculative*, mediated touch by means of tactile or force feedback allows for controlled experiments on how people respond to and experience being touched by another person, research which currently relies almost exclusively on people's responses to pictures or movies in which people are touched (see Sect. 4.2). This would further extend the application of advanced media environments as tools in the service of psychological experimentation, where one can benefit from a combination of full experimental control and high ecological validity (see Ref. [115] and [116], presenting a similar argument for using virtual environments as research tools in social psychology and environmental psychology, respectively).

Other interesting questions that present themselves focus on how the design of communication devices based on physical interaction can benefit from recent knowledge on multimodal perception and crossmodal transfer, especially by combining touch with appropriate visual feedback (see Sect. 3). In our own labs, for example, we are currently exploring these questions by means of the recently discovered rubber hand illusion [117]. This illusion illustrates that we can integrate technological devices as a phenomenal extension of the self, and a better understanding of the illusion might enable genuine embodied interaction with technology, perhaps eventually blurring the boundary between our 'unmediated' self and the 'mediating' technology (e.g., [118]).

Several measures are currently available that have potential relevance for investigating the presumed effects of haptic communication media, such as social presence measures (for an overview, see Ref. [81]), the affective benefits and cost in communication questionnaire (i.e., ABC–Q, [119]), behavioral indicators of social perception (e.g., responses to personal space violations; [120]), or psychophysiological indicators of affective responses. The extent to which mediated haptic interactions can elicit relevant social evaluations or responses will testify to the quality of the social touch simulation, and the appropriateness of the mediated touch metaphor.

To conclude, the studies reviewed in the present paper show a diverse range of promising applications of mediated social touch, ranging from the communication of simple ideas through tactile symbols (e.g., the FootIO, [90], or the LoveBomb, [104]), to providing a sense of awareness (e.g., Shaker; [106]) and facilitating the recovery from stress (e.g., the PillO'Mate, [107]). However, to date, the assumed effects of mediated social touch on interpersonal interaction have not been submitted to empirical scrutiny for the majority of the systems discussed here (for exceptions see Ref. [6, 110]), and design approaches have typically been theoretically amorphous. The significance of mediated social touch needs to be empirically established, and grounded within a multidisciplinary theoretical framework that encompasses multisensory perception, social psychology, and communication theory.

References

1. Holmes NP, Spence C (2004) The body schema and multisensory representation(s) of peripersonal space. Cogn Process 5:94–105 DOI 10.1007/s10339-004-0013-3
2. Montagu A, Matson FW (1979) The human connection. McGraw-Hill, NY
3. Jones SE, Yarbrough AE (1985) A naturalistic study of the meanings of touch. Commun Monogr 52:19–56
4. Register LM, Henley TB (1992) The phenomenology of intimacy. J Soc Pers Relat 9:467–481
5. Crusco AH, Wetzel CG (1984) The Midas touch: the effects of interpersonal touch on restaurant tipping. Pers Soc Psychol Bull 10:512–517
6. Brave S, Nass C, Sirinian E (2001) Force-feedback in computer-mediated communication. In: Universal access in HCI: towards an information society for all, vol 3. Stephanidis C (ed) Lawrence Erlbaum, Hillsdale, NJ
7. Loomis JM, Lederman SJ (1982) What utility is there in distinguishing between active and passive touch? Paper presented at the Psychonomic Society meeting, November 1984, San Antonio, TX
8. Loomis JM, Lederman SJ (1986) Tactual perception. In: Handbook of perception and human performance: vol 2, cognitive processes and performances. Boff KR, Kaufman L, Thomas JP (eds) Wiley, NY
9. Klatzky RL, Lederman SJ (2003) Touch. In: Handbook of psychology: vol 4, experimental psychology. Wiener IB (series ed) Healy AF, Proctor RW (vol eds) Wiley, NY
10. Johnson KO (2001) The roles and functions of cutaneous mechanoreceptors. Curr Opin Neurobiol 11:455–461 DOI 10.1016/S0959-4388(00)00234-8
11. Johnson KO, Yoshioka T, Vega-Bermudez F (2000) Tactile functions of mechanoreceptive afferents innervating the hand. J Clin Neurophysiol 17:539–558
12. Sherrick CE, Cholewiak RW (1986) Cutaneous sensitivity. In: Handbook of perception and human performance: vol 1, sensory processes and perception. Boff KR, Kaufman L, Thomas JP (eds) Wiley, NY

13. Clark FJ, Horch KW (1986) Kinesthesia. In: Handbook of perception and human performance: vol 1, sensory processes and perception. Boff KR, Kaufman L, Thomas JP (eds) Wiley, NY
14. Weber EH (1996) De pulsu, resorptione, audita et tactu. Annotationes anatomicae et physiologicae. In: E. H. Weber on the tactile senses 2nd edn. Ross HE, Murray DJ (eds & trans) Taylor & Francis, Hove, UK (Original work published 1834)
15. Biggs J, Srinivasan MA (2002) Haptic interfaces. In: Stanney KM (ed) Handbook of virtual environments. Lawrence Erlbaum, London
16. Burdea GC (1996) Force and touch feedback for virtual reality. Wiley, NY
17. Kaczmarek KA, Bach-y-Rita P (1995) Tactile displays. In: Barfield W, Furness T (eds) Virtual environments and advanced interface design. Oxford University Press, NY
18. Kaczmarek KA, Webster JG, Bach-y-Rita P, Tompkins WJ (1991) Electrotactile and vibrotactile displays for sensory substitution systems. IEEE Trans Biomed Eng 38:1–16 DOI 10.1109/10.68204
19. Bach-y-Rita P, Kercel SW (2003) Sensory substitution and the human-machine interface. Trends Cogn Sci 7:541–546 DOI 10.1016/j.tics.2003.10.013
20. Caldwell G, Gosney C (1993) Enhanced tactile feedback (tele-taction) using a multi-functional sensory system. In: Proceedings of ICRA 1993. DOI 10.1109/ROBOT.1993.292099
21. Ino S, Shimizu S, Odagawa T, Sato M, Takahashi M, Izumi T, Ifukube T (1993) A tactile display for presenting quality of materials by changing the temperature of skin surface. In: Proceedings of RO-MAN 1993. DOI 10.1109/RO-MAN.1993.367718
22. Ottensmeyer MP, Salisbury JK (1997) Hot and cold running VR: adding thermal stimuli to the haptic experience. In: Proceedings of the 2nd PHANToM users group workshop, October 19–22, 1997, Endicott House, Dedham, MA
23. Bouzit M, Burdea G, Popescu G, Boian R (2002) The Rutgers Master II: new design force-feedback glove. IEEE/ASME Trans Mechatronics 7:256–263 DOI 10.1109/TMECH.2002.1011262
24. Massie TH, Salisbury JK (1994) The PHANTOM haptic interface: a device for probing virtual objects. In: Proceedings of the ASME winter annual meeting, symposium on haptic interfaces for virtual environment and teleoperator systems, November 1994, Chicago, IL
25. Van der Linde RQ, Lammertse P, Frederiksen E, Ruiter B (2002) The HapticMaster, a new high-performance haptic interface. In: Proceedings of EuroHaptics 2002. Wall SA, Riedel B, Crossan A, McGee MR (eds)
26. Biocca F, Kim J, Choi Y (2001) Visual touch in virtual environments: an exploratory study of presence, multimodal interfaces, and cross-modal sensory illusions. Presence: Teleoperators Virtual Environ 10:247–265
27. Van Mensvoort K (2002) What you see is what you feel: exploiting the dominance of the visual over the haptic domain to simulate force-feedback with cursor displacements. In: Proceedings of DIS '02. ACM Press, NY. DOI 10.1145/778712.778761
28. Geldard FA (1960) Some neglected possibilities of communication. Science 131:1583–1588
29. Geldard FA (1967) Pattern perception by the skin. In: The skin senses. Kenshalo DR (ed) Charles C Thomas, Springfield, IL
30. Brewster S, Brown LM (2004) Tactons: structured tactile messages for non-visual information display. In: ACM international conference proceeding Series: vol 53, proceedings of the Fifth Australasian user interface conference, vol 28. Cockburn A (ed) ACM Press, NY
31. Enriquez MJ, MacLean KE (2003) The hapticon editor: a tool in support of haptic communication research. In: Proceedings of Haptics 2003. DIO 10.1109/HAPTIC.2003.1191310
32. MacLean KE, Enriquez MJ (2003) Perceptual design of haptic icons. In: Proceedings of Eurohaptics 2003. Oakley I, O'Modhrain S, Newell F (eds)
33. van Erp JBF, Spapé MMA (2003) Distilling the underlying dimensions of tactile melodies. In: Proceedings of Eurohaptics 2003. Oakley I, O'Modhrain S, Newell F (eds)
34. Oakley I, McGee MR, Brewster S, Gray P (2000) Putting the feel in 'look and feel'. In: Proceedings of CHI 2000, ACM Press, NY. DOI 10.1145/332040.332467
35. Toney A, Mulley B, Thomas BH, Piekarski W (2003) Social weight: designing to minimise the social consequences arising from technology use by the mobile professional. Pers Ubiquitous Comput 7:309–320 DOI 10.1007/s00779-003-0245-8
36. van Erp JBF, van Veen HAHC (2003) A multi-purpose tactile vest for astronauts in the International Space Station. In: Proceedings of Eurohaptics 2003. Oakley I, O'Modhrain S, Newell F (eds)
37. van Erp JBF (2005) Presenting directions with a vibrotactile torso display. Ergonomics 48:302–313 DOI 10.1080/00140130420003 27670
38. Stone RJ (2001) Haptic feedback: a brief history from telepresence to virtual reality. In: Lecture notes in computer science: vol 2058, proceedings of the first international workshop on haptic human-computer interaction. Brewster S, Murray-Smith R (eds) Springer, Berlin, Germany
39. Epstein W, Hughes B, Schneider S, Bach-y-Rita P (1986) Is there anything out there? A study of distal attribution in response to vibrotactile stimulation. Perception 15:275–284
40. Loomis JM (1992) Distal attribution and presence. Presence: Teleoperators Virtual Environ 1:113–119
41. Holland KL, Williams II RL, Conatser Jr. RR, Howell JN, Cade DL (2004) The implementation and evaluation of a virtual haptic back. Virtual Real 7:94–102 DOI 10.1007/s10055-003-0118-5
42. Hoffman HG, Garcia-Palacios A, Carlin A, Furness III TA, Botella-Arbona C (2003) Interfaces that heal: coupling real and virtual objects to treat spider phobia. Int J Hum Comput Interact 16:283–300 DOI 10.1207/S15327590IJHC1602_08
43. Srinivasan MA, Basdogan C (1997) Haptics in virtual reality: taxonomy, research status, and challenges. Comput Graph 21:393–404 DOI 10.1016/S0097-8493(97)00030-7
44. IJsselsteijn WA (2004) Presence in depth. Eindhoven University of Technology, Eindhoven, The Netherlands
45. IJsselsteijn WA, Reiner M (2004) On the importance of reliable real-time sensorimotor dependencies for establishing telepresence. In: Proceedings of Presence 2004. Alcañiz Raya M, Solaz BR (eds)
46. Reiner M (2004) The role of haptics in immersive telecommunication environments. IEEE Trans Circuits Syst Video Technol 14:392–401 DOI 10.1109/TCSVT.2004.823399
47. Basdogan C, Ho C, Srinivasan MA, Slater M (2000) An experimental study on the role of touch in shared visual environments. ACM Trans Comput Hum Interact 7:443–460 DOI 10.1145/365058.365082
48. Sallnäs E, Rassmus-Gröhn K, Sjöström C (2000) Supporting presence in collaborative environments by haptic force feedback. ACM Trans Comput Hum Interact 7:461–476 DOI 10.1145/365058.365086
49. Schiff W, Foulke E (eds) (1982) Tactual perception: a sourcebook. Cambridge University Press, Cambridge, UK
50. Goffman E (1959) The presentation of self in everyday life rev edn. Doubleday, NY
51. Thayer S (1982) Social touching. In: Tactual perception: a sourcebook. Schiff W, Foulke E (eds) Cambridge University Press, Cambridge, UK
52. Field T (2003) Touch. MIT Press, Cambridge, MA
53. Montagu A (1986) Touching: the human significance of the skin 3rd edn. Harper and Row, NY
54. Mead GH, Morris CW (ed) (1934) Mind, self, and society, from the standpoint of a social behaviorist. The University of Chicago Press, Chicago

55. Blumer H, Morrione TJ (ed) (2004) George Herbert Mead and human conduct. AltaMira Press, Walnut Creek, CA
56. Burgoon JK (1994) Nonverbal signals. In: Handbook of interpersonal communication 2nd edn. Knapp ML, Miller GR (eds) Sage Publications, Thousand Oaks, CA
57. Manusov V, Rodriguez JS (1989) Intentionality behind nonverbal messages: a perceiver's perspective. J Nonverbal Behav 13:15–24 DOI 10.1007/BF01006470
58. Burgoon JK, Newton DA (1991) Applying a social meaning model to relational messages of conversational involvement: comparing participant and observer perspectives. South Commun J 56:96–113
59. Burgoon JK, Walther JB, Baesler EJ (1992) Interpretations, evaluations, and consequences of interpersonal touch. Hum Commun Res 19:237–263
60. Burgoon JK (1991) Relational message interpretations of touch, conversational distance, and posture. J Nonverbal Behav 15:233–259 DOI 10.1007/BF00986924
61. Burgoon JK, Walther JB (1990) Nonverbal expectancies and the evaluative consequences of violations. Hum Commun Res 17:232–265
62. Floyd K (1999) All touches are not created equal: effects of form and duration on observers' interpretations of an embrace. J Nonverbal Behav 23:283–299 DOI 10.1023/A:1021602926270
63. Henley NM (1973) Status and sex: some touching observations. Bulletin of the Psychon Soc 2:91–93
64. Goffman E (1961) Encounters: two studies in the sociology of interaction. Bobbs-Merrill, Indianapolis, IN
65. Jourard SM, Rubin JE (1968) Self-disclosure and touching: a study of two modes of interpersonal encounter and their interrelation. J Humanist Psychol 8:39–48
66. Fisher JD, Rytting M, Heslin R (1967) Hands touching hands: affective and evaluative effects of an interpersonal touch. Sociometry 39:416–421
67. Hornik J (1992) Tactile stimulation and consumer response. J Consu Res 19:449–458
68. Patterson ML, Powell JL, Lenihan MG (1986) Touch, compliance, and interpersonal affect. J Nonverbal Behav 10:41–50 DOI 10.1007/BF00987204
69. Guéguen N (2002) Kind of touch and compliance with a request. Stud Psychol 44:167–172
70. Kleinke CL (1977) Compliance to a request made by gazing and touching experimenters in field settings. J Exp Soc Psychol 13:18–223
71. Nannberg JC, Hansen CH (1994) Post-compliance touch: an incentive for task performance. J Soc Psychol 134:301–307
72. Goldman M, Fordyce J (1983) Prosocial behavior as affected by eye contact, touch and voice expression. J Soc Psychol 121:125–129
73. Guéguen N, Fisher-Lokou J (2003) Tactile contact and spontaneous help: an evaluation in a natural setting. J Soc Psychol 143:785–787
74. Paulsell S, Goldman M (1984) The effect of touching different body areas on prosocial behavior. J Soc Psychol 122:269–273
75. Guéguen N (2002) Touch, awareness of touch and compliance with a request. Percept Mot Skills 95:355–360
76. Guéguen N (2004) Nonverbal encouragement of participation in a course: the effect of touching. Soc Psychol Educ 7:89–98 DOI 10.1023/B:SPOE.0000010691.30834.14
77. Guéguen N, Jacob C (2005) The effect of touch on tipping: an evaluation in a French bar. Int J Hospitality Manage 24:295–299 DOI 10.1016/j.ijhm.2004.06.004
78. Kaufman D, Mahoney JM (1999) The effects of waitresses' touch on alcohol consumption in dyads. J Soc Psychol 139:261–267
79. Clark HH, Brennan SE (1991) Grounding in communication. In: Perspectives on socially shared cognition. Resnick LB, Levine JM, Teasley SD (eds) American Psychological Association, Washington, DC
80. Daft RL, Lengel RH (1986) Organizational information requirements, media richness and structural design. Manage Sci 32:554–571
81. Biocca F, Harms C, Burgoon JK (2003) Towards a more robust theory and measure of social presence: review and suggested criteria. Presence: Teleoperators Virtual Environ 12:456–480
82. Short J, Williams E, Christie B (1976) The social psychology of telecommunications. Wiley, London
83. Hoyt CL, Blascovich J, Swinth KR (2003) Social inhibition in immersive virtual environments. Presence Teleoperators Virtual Environ 12:183–195
84. Blascovich J (2002) A theoretical model of social influence for increasing the utility of collaborative virtual environments. In: Proceedings of CVE 2002. ACM Press, NY. DOI 10.1145/571878.571883
85. Brave S, Dahley A (1997) InTouch: a medium for haptic interpersonal communication. In: Extended abstracts of CHI 1997. ACM Press, NY
86. Chang A, O'Modhrain S, Jacob R, Gunther E, Hiroshi I (2002) ComTouch: design of a vibrotactile communication device. In: Proceedings of DIS 2002. ACM Press, NY. DOI 10.1145/778712.778755
87. Chang A, Kanji Z, Ishii H (2001) Designing touch-based communication devices. In: Proceedings of Workshop No. 14: Universal design: towards universal access in the information society, organized in the context of CHI 2001, March 31–April 5, 2001, Seattle, WA
88. Rovers AF, van Essen HA (2004) Design and evaluation of hapticons for enriched instant messaging. In: Proceedings of EuroHaptics 2004. Buss M, Fritschi M, Esen H. (eds)
89. Rovers AF, van Essen HA (2004) HIM: a framework for haptic instant messaging. In: Extended abstracts of CHI 2004. ACM Press, NY. DOI 10.1145/985921.986052
90. Rovers AF, van Essen HA (2005) FootIO: design and evaluation of a device to enable foot interaction over a computer network. In: Proceedings of WHC 2005. DOI 10.1109/WHC.2005.56
91. van Essen HA, Rovers AF (2005) Layered protocols approach to analyze haptic communication over a network. In: Proceedings of WHC 2005. DOI 10.1109/WHC.2005.85
92. Chan A, MacLean K, McGrenere J (2005) Learning and identifying haptic icons under workload. In: Proceedings of WHC 2005. DOI 10.1109/WHC.2005.86
93. DiSalvo C, Gemperle F, Forlizzi J, Montgomery E (2003) The Hug: an exploration of robotic form for intimate communication. In: Proceedings of RO-MAN 2003. DOI 10.1109/ROMAN.2003.1251879
94. Gemperle F, DiSalvo C, Forlizzi J, Yonkers W (2003) The Hug: a new form for communication. In: Proceedings of DUX 2003. ACM Press, NY. DOI 10.1145/997078.997103
95. Mueller F, Vetere F, Gibbs MR, Kjeldskov J, Pedell S, Howard S (2005) Hug over a distance. In: Extended abstracts of CHI 2005. ACM Press, NY. DOI 10.1145/1056808.1056994
96. Ishii H, Ullmer B (1997) Tangible bits: towards seamless interfaces between people, bits and atoms. In: Proceedings of CHI 1997. Pemberton S (ed) ACM Press, NY. DOI 10.1145/258549.258715
97. Brave S, Ishii H, Dahley A (1998) Tangible interface for remote collaboration and communication. In: Proceedings of CSCW 1998. ACM Press, NY. DOI 10.1145/289444.289491
98. Tollmar K, Junestrand S, Torgny O (2000) Virtual living together: a design framework for new communication media. In: Proceedings of DIS 2000. Boyarski D, Kellogg WA (eds) ACM Press, NY. DOI 10.1145/347642.347670
99. Gaver B (2002) Provocative awareness. Comput Support Coop Work 11:475–493 DOI 10.1023/A:1021277326673
100. IJsselsteijn WA, van Baren J, van Lanen F (2003) Staying in touch: social presence and connectedness through synchronous and asynchronous communication media. In: Human-computer interaction: vol 2, theory and practice part II. Stephanidis C, Jacko J (eds) Lawrence Erlbaum, Mahwah, NJ
101. Shanken EA (2000) Tele-agency: telematics, telerobotics, and the art of meaning. Art J 59(2):64–77

102. Fogg BJ, Cutler LD, Arnold P, Eisbach C (1998) HandJive: a device for interpersonal entertainment. In: Proceedings of CHI 1998. Atwood ME, Karat C, Lund A, Coutaz J, Karat J (eds) ACM Press, NY. DOI 10.1145/274644.274653
103. Dobson K, Boyd D, Ju W, Donath J, Ishii H (2001) Creating visceral personal and social interactions in mediated spaces. In: Extended abstracts of CHI 2001. ACM Press, NY. DOI 10.1145/634067.634160
104. Hansson R, Skog T (2001) The LoveBomb: encouraging the communication of emotions in public spaces. In: Extended abstracts of CHI 2001. ACM Press, NY. DOI 10.1145/634067.634319
105. Oakley I, O'Modhrain S (2002) Contact IM: exploring asynchronous touch over distance. In: Proceedings of CSCW 2002, November 16–20, 2002, New Orleans, LA
106. Strong R, Gaver B (1996) Feather, Scent and Shaker: supporting simple intimacy. Short paper presentation at CSCW 1996, November 16–20, 1996, Boston, MA
107. McGee K, Harrup A (2003) Contact expressions for touching technologies. In: Proceedings of COSIGN 2003. Mitchell G (ed) University of Teesside, Teesside, UK
108. Alhalabi MO, Horiguchi S (2001) Tele-Handshake: a cooperative haptic shared virtual environment. In: Proceedings of Eurohaptics 2001. Baber C, Faint M, Wall S, Wing AM (eds)
109. Oakley I, Brewster SA, Gray PD (2000) Communicating with feeling. In: Lecture Notes in Computer Science, vol 2058. Proceedings of the First Workshop on Haptic Human-Computer Interaction. Brewster SA, Murray-Smith R (eds) ACM Press, NY
110. Oakley I, Brewster SA, Gray P (2001) Can you feel the force? An investigation of haptic collaboration in shared editors. In: Proceedings of Eurohaptics 2001. Baber C, Faint M, Wall S, Wing AM (eds)
111. Gumtau S (2005) Tactile semiotics: the meanings of touch explored with low-tech prototypes. In: Proceedings of WHC 2005. DOI 10.1109/WHC.2005.124
112. Brown LM, Brewster SA, Purchase HC (2005) A first investigation into the effectiveness of tactons. In: Proceedings of WHC 2005. DOI 10.1109/WHC.2005.6
113. Heslin R, Nguyen TD, Nguyen ML (1983) Meaning of touch: the case of touch from a stranger or same sex person. J Nonverbal Behav 7:147–157 DOI 10.1007/BF00986945
114. Floyd K (2000) Affectionate same-sex touch: the influence of homophobia on observers' perceptions. J Soc Psychol 140:774–788
115. Loomis JM, Blascovich JJ, Beall AC (1999) Immersive virtual environment technology as a basic research tool in psychology. Behav Res Methods Instrum Comput 31:557–564
116. de Kort YAW, IJsselsteijn WA, Kooijmans J, Schuurmans Y (2003) Virtual environments as a research tool for environmental psychology: a study of the comparability of real and virtual environments. Presence: Teleoperators Virtual Environ 12:360–373
117. Botvinick M, Cohen J (1998) Rubber hands 'feel' touch that eyes see. Nature 391:756 DOI 10.1038/35784
118. IJsselsteijn WA, de Kort YAW, Haans A (2005) Is this my hand I see before me? The rubber hand illusion in reality, virtual reality, and mixed reality. In: Proceedings of Presence 2005. Slater M (ed) University College London, London
119. van Baren J, IJsselsteijn WA, Markopoulos P, Romero N, de Ruyter B (2004) Measuring affective benefits and costs of awareness systems supporting intimate social networks. In: CTIT workshop proceedings series: vol 2, Proceedings of SID 2004. Nijholt A, Nishida T (eds)
120. Bailenson JN, Blascovich J, Beall AC, Loomis JM (2003) Interpersonal distance in immersive virtual environments. Pers Soc Psychol Bull 29:819–833 DOI 10.1177/0146167203029007002
121. Sherrington C (1961) The integrative action of the nervous system 2nd edn. Yale University Press, New Haven, CT
122. Watzlawick P, Bavelas JB, Jackson DD (1967) Pragmatics of human communication: a study of interactional patterns, pathologies, and paradoxes. Norton, NY