

Social touch in human–computer interaction

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Touch is our primary non-verbal communication channel for conveying intimate emotions and as such essential for our physical and emotional wellbeing. In our digital age, human social interaction is often mediated. However, even though there is increasing evidence that mediated touch affords affective communication, current communication systems (such as videoconferencing) still do not support communication through the sense of touch. As a result, mediated communication does not provide the intense affective experience of co-located communication. The need for ICT mediated or generated touch as an intuitive way of social communication is even further emphasized by the growing interest in the use of touch-enabled agents and robots for healthcare, teaching, and telepresence applications. Here, we review the important role of social touch in our daily life and the available evidence that affective touch can be mediated reliably between humans and between humans and digital agents. We base our observations on evidence from psychology, computer science, sociology, and neuroscience with focus on the first two. Our review shows that mediated affective touch can modulate physiological responses, increase trust and affection, help to establish bonds between humans and avatars or robots, and initiate pro-social behavior. We argue that ICT mediated or generated social touch can (a) intensify the perceived social presence of remote communication partners and (b) enable computer systems to more effectively convey affective information. However, this research field on the crossroads of ICT and psychology is still embryonic and we identify several topics that can help to mature the field in the following areas: establishing an overarching theoretical framework, employing better research methodologies, developing basic social touch building blocks, and solving specific ICT challenges.

Keywords: affective touch, mediated touch, social touch, interpersonal touch, human–computer interaction, human–robot interaction, haptic, tactile

Introduction

Affective Touch in Interpersonal Communication

The sense of touch is the earliest sense to develop in a human embryo (Gottlieb 1971) and is critical for mammals' early social development and to grow up healthily (Harlow and Zimmermann 1959; Montagu 1972). The sense of touch is one of the first mediums of communication between newborns and parents. Interpersonal communication is to a large extent non-verbal and one of the primary purposes of non-verbal behavior is to communicate emotional states. Non-verbal communication includes facial expressions, prosody, gesture, and touch

(Argyle 1975; Knapp and Hall 2010) of which touch is the primary modality for conveying intimate emotions (Field 2010; Morrison et al. 2010; App et al. 2011), for instance, in greetings, in corrections, and in (sexual) relationships. As touch implies direct physical interaction and co-location, it inherently has the potential to elicit feelings of social presence. The importance of touch as a modality in social communication is highlighted by the fact that the human skin has specific receptors to process affective touch (“the skin as a social organ”: Morrison et al. 2010) in addition to those for discriminative touch (Löken et al. 2009; Morrison et al. 2011; Gordon et al. 2013; McGlone et al. 2014), presumably like all mammals (Vrontou et al. 2013). ICT systems can employ human touch for information processing (discriminative touch) and communication (social touch) as well.

Discriminative Touch in ICT Systems

Conventional systems for human–computer interaction only occasionally employ the sense of touch and mainly provide information through vision and audition. One of the first large-scale applications of a tactile display was the vibration function on mobile phones, communicating the 1-bit message of an incoming call, and the number of systems that include the sense of touch has steadily increased over the past two decades. An important reason for the sparse use of touch is the supposed low bandwidth of the touch channel (Gallace et al. 2012). Although often underestimated, our touch sense is very well able to process large amounts of abstract information. For instance, blind people who are trained in Braille reading can actually read with their fingertips. This information processing capability is increasingly applied in our interaction with systems, and more complex information is being displayed, e.g., to reduce the risk of visual and auditory overload in car driving, to make us feel more immersed in virtual environments, or to realistically train and execute certain medical skills (van Erp and van Veen 2004; Self et al. 2008).

Affective Touch in ICT Systems

Incorporating the sense of touch in ICT systems started with discriminative touch as an information channel, often in addition to vision and audition (touch for information processing). We believe that we are on the verge of a second transition: adding social or affective touch to ICT systems (touch for social communication). In our digital era, an increasing amount of our social interactions is mediated, for example, through (cell) phones, video conferencing, text messaging, chat, or e-mail. Substituting direct contact, these modern technologies make it easy to stay in contact with distant friends and relatives, and they afford some degree of affective communication. For instance, an audio channel can transmit affective information through phonetic features like amplitude variation, pitch inflections, tempo, duration, filtration, tonality, or rhythm, while a video channel supports non-verbal information such as facial expressions and body gestures. However, current communication devices do not allow people to express their emotions through touch and may therefore lack a convincing experience of actual togetherness (social presence). This technology-induced touch deprivation may even degrade the potential beneficial effects of mediated social interaction [for reviews of the negative side effects of touch deprivation see

Field (2010) and Gallace and Spence (2010)]. For these reasons, mediated interpersonal touch is our first topic of interest.

Human–computer interaction applications increasingly deploy intelligent agents to support the social aspects of the interaction. Social agents (either embodied or virtual) already employ vision and audition to communicate social signals but generally lack touch capabilities. If we look at applications in robots and avatars, the first applications including touch facilitated information from user to system only, e.g., in the form of a touch screen or through specific touch sensors in a tangible interface. Social agents that can touch the user are of much more recent date. We believe that social agents could benefit from generating and perceiving social touch cues (van Erp 2012). Based on studies reviewed in this paper, we expect that people will feel a closer bond with agents or robots that use and respond to affective touch since they appear more human than machine-like and more trustworthy. Touch-enabled social agents are therefore our second topic of interest.

Touch in Social Communication

Social touch can take many forms in our daily lives such as greetings (shaking hands, embracing, kissing, backslapping, and cheek-tweaking), in intimate communication (holding hands, cuddling, stroking, back scratching, massaging), and in corrections (punishment, spank on the bottom). Effects of social touch are apparent at many levels ranging from physiology to social behavior as we will discuss in the following sections.

Social touches can elicit a range of strong experiences between pleasant and unpleasant, depending on among others the stimulus [e.g., unpleasant pinches evoking pain (nociception)] and location on the body (e.g., pleasant strokes in erogenous zones). In addition to touch in communication, touch can also be employed in psychotherapy (Phelan 2009) and nursing (Gleeson and Timmins 2005). Examples range from basic comforting touches and massaging to alternative therapies such as acu-pressure, Reiki, vibroacoustic therapy, and low-frequency vibration (Wigram 1996; Kvam 1997; Patrick 1999; Puhan et al. 2006; Prisby et al. 2008). See Dijk et al. (2013) for more examples on mental, health-related, and bodily effects of touch. In this paper, we focus on ICT mediated and generated social touch (the areas where psychology and computer science meet), meaning that areas of, for instance, Reiki and low-frequency vibration fall outside the scope of this paper. We first discuss the many roles of social touch in our daily life before continuing with ICT mediated inter-human touch and ICT generated and interpreted touch in human–agent interaction.

In 1990s (Vallbo et al. 1993), the first reports on so-called C tactile afferents in human hairy skin were published. This neurophysiological channel in the skin reacts to soft, stroking touches, and its activity strongly depends on stroking speed (with an optimum in the speed range 3–10 cm/s) and has a high correlation with subjective ratings of the pleasantness of the touch. Research over the past decades has shown that this system is not involved in discriminative touch (Olausson et al. 2008) but underlies the emotional aspects of touch and the development and function of the social brain (McGlone et al. 2014). Social touches may activate both this pleasurable touch system and the discriminative touch

system (reacting to, for instance, pressure, vibration, and skin stretch).

Touch, Physiological Functioning, and Wellbeing

McCance and Otley (1951) showed that licking and stroking of the mother animal is critical to start certain physiological processes in a new-born mammal. This indicates the direct link between skin stimulation and physiological processes, a link that is preserved later in life. For instance, gentle stroking touch can lower heart rate and blood pressure (Grewen et al. 2003), increase transient sympathetic reflexes and increase pain thresholds (Drescher et al. 1980; Uvnäs-Moberg 1997), and affect the secretion of stress hormones (Whitcher and Fisher 1979; Shermer 2004; Ditzen et al. 2007). Women holding their partner's hand showed attenuated threat-related brain activity in response to mild electric shocks (Coan et al. 2006) and reported less pain in a cold pressor task (Master et al. 2009). Touch can also result in coupling or syncing of electrodermal activity of interacting (romantic) couples (Chatel-Goldman et al. 2014). Interpersonal touch is the most commonly used method of comforting (Dolin and Booth-Butterfield 1993) and an instrument in nursing care (Bush 2001, Chang 2001, Henricson et al. 2008). For example, patients who were touched by a nurse during preoperative instructions experienced lower subjective and objective stress levels (Whitcher and Fisher 1979), than people who were not.

In addition to touch affecting hormone levels, hormones (i.e., oxytocin) also affect the perception of interpersonal touch. Scheele et al. (2014) investigated the effect of oxytocin on the perception of a presumed male or female touch on male participants and found that oxytocin increased the rated pleasantness and brain activity of presumed female touches but not of male touches (all touches were delivered by the same female experimenter). Ellingsen et al. (2014) reported that after oxytocin submission, the effect of touch on the evaluation of facial expression increased. In addition, touch (handshaking in particular) can also play a role in social chemo-signaling. Handshaking can lead to the exchange of chemicals in sweat and behavioral data indicates that people more often sniff their hands after a greeting with a handshake than without a handshake (Frumin et al. 2015). Many social touches are reciprocal in nature (like cuddling and holding hands) and their dynamics rely on different mechanisms all having their own time scale: milliseconds for the detection of a touch (discriminative touch), hundreds of milliseconds and up for the experience of pleasurable touch, and seconds and up for physiological responses (including changes in hormone levels). How these processes interact and possibly reinforce each other is still terra incognita.

Physiological responses can also be indirect, i.e., the result of social or empathetic mechanisms. Cooper et al. (2014) recently showed that the body temperature of people decreased when looking at a video of other people putting their hands in cold water. Another recent paradigm is to use thermal and haptically enhanced interpersonal speech communication. This showed that warm and cold signals were used to communicate the valence of messages (Ijzerman and Semin 2009; Suhonen et al. 2012a). Warm messages were used to emphasize positive feelings and pleasant experiences, and to express empathy, comfort, closeness,

caring, agreement, gratitude, and moral support. Cold feedback was consistently associated with negative issues.

Touch to Communicate Emotions

Hertenstein et al. (2006, 2009) showed that touch alone can effectively be used to convey distinct emotions such as anger, fear, and disgust. In addition, touch plays a role in communicating more complex social messages like trust, receptivity, affection (Mehrabian 1972; Burgoon 1991) and nurture, dependence, and affiliation (Argyle 1975). Touch can also enhance the meaning of other forms of verbal and non-verbal communication, e.g., touch amplifies the intensity of emotional displays from our face and voice (Knapp and Hall 2010). Examples of touches used to communicate emotions are shaking, pushing, and squeezing to communicate anger, hugging, patting, and stroking to communicate love (Gallace and Spence 2010). Jones and Yarbrough (1985) stated that a handshake, an encouraging pat on the back, a sensual caress, a nudge for attention, a tender kiss, or a gentle brush of the shoulder can all convey a vitality and immediacy that is at times far more powerful than language. According to App et al. (2011), touch is the preferred non-verbal communication channel for conveying intimate emotions like love and sympathy, confirmed by, for instance, Debrot et al. (2013) who showed that responsive touch between romantic partners enhances their affective state.

Touch to Elicit Emotions

Not only can the sense of touch be used to communicate distinct emotions but also to elicit (Suk et al. 2009) and modulate human emotion. Please note that interpreting communicated emotions differs from eliciting emotions as the former may be considered as a cognitive task not resulting in physiological responses, e.g., one can perceive a touch as communicating anger without feeling angry. Starting with the James–Lange theory (James 1884; Cannon 1927; Damasio 1999), the conscious experience of emotion is the brain's interpretation of physiological states. The existence of specific neurophysiological channels for affective touch and pain and the direct physiological reactions to touch indicate that there may be a direct link between tactile stimulation, physiological responses, and emotional experiences. Together with the distinct somatotopic mapping between bodily tactile sensations and different emotional feelings as found by Nummenmaa et al. (2013), one may assume that tactile stimulation of different bodily regions can elicit a wide range of emotions.

Touch as a Behavior Modulator

In addition to communicating and eliciting emotions, touch provides an effective means of influencing people's attitudes toward persons, places, or services, their tendency to create bonds and their (pro-)social behaviors [see Gallace and Spence (2010) for an excellent overview]. This effect is referred to as the Midas touch: a brief, casual touch (often at the hand or arm) that is not necessarily consciously perceived named after king Midas from Greek mythology who had the ability to turn everything he touched into gold. For example, a half-second of hand-to-hand touch from a librarian fostered more favorable impressions of the library (Fisher et al. 1976), touching by a salesperson increased positive evaluations of the store (Hornik 1992), and touch can

also boost the attractiveness ratings of the toucher (Burgoon et al. 1992). Recipients of such “simple” Midas touches are also more likely to be more compliant or unselfish: willing to participate in a survey (Guéguen 2002) or to adhere to medication (Guéguen et al. 2010), volunteering for demonstrating in a course (Guéguen 2004), returning money left in a public phone (Kleinke 1977), spending more money in a shop (Hornik 1992), tipping more in a restaurant (Crusco and Wetzel 1984), helping with picking-up dropped items (Guéguen and Fischer-Lokou 2003), or giving away a cigarette (Joule and Guéguen 2007). In addition to these one-on-one examples, touch also plays a role in teams. For instance, physical touch enhances team performance of basketball players through building cooperation (Kraus et al. 2010). In clinical and professional situations, interpersonal touch can increase information flow and causes people to evaluate communication partners more favorably (Fisher et al. 1976).

Mediated Social Touch

In the previous section, we showed that people communicate emotions through touch, and that inter-human touch can enhance wellbeing and modulate behavior. In interpersonal communication, we may use touch more frequently than we are aware of. Currently, interpersonal communication is often mediated and given the inherent human need for affective communication, mediated social interaction should preferably afford the same affective characteristics as face-to-face communication. However, despite the social richness of touch and its vital role in human social interaction, existing communication media still rely on vision and audition and do not support haptic interaction. For a more in-depth reflection on the general effects of mediated interpersonal communication, we refer to Konijn et al. (2008) and Ledbetter (2014).

Tactile or kinesthetic interfaces in principle enable haptic communication between people who are physically apart, and may thus provide mediated social touch, with all the physical, emotional, and intellectual feedback it supplies (Cranny-Francis 2011). Recent experiments show that even simple forms of mediated touch have the ability to elicit a wide range of distinct affective feelings (Tsalamlal et al. 2014). This finding has stimulated the study and design of devices and systems that can communicate, elicit, enhance, or influence the emotional state of a human by means of mediated touch.

Remote Communication Between Partners

Intimacy is of central importance in creating and maintaining strong emotional bonds. Humans have an important social and personal need to feel connected in order to maintain their interpersonal relationships (Kjeldskov et al. 2004). A large part of their interpersonal communication is emotional rather than factual (Kjeldskov et al. 2004).

The vibration function on a mobile phone has been used to render emotional information for blind users (Réhman and Liu 2010) and a similar interface can convey emotional content in instant messaging (Shin et al. 2007). Also, a wide range of systems have been developed for the mediated representation of specific touch events between dyads such as kisses (Saadatian et al. 2014), hugs (Mueller et al. 2005; Cha et al. 2008; Teh et al. 2008; Gooch

and Watts 2010; Tsetserukou 2010), pokes (Park et al. 2011), handholding (Gooch and Watts 2012; Toet et al. 2013), handshakes (Bailenson et al. 2007), strokes on the hand (Eichhorn et al. 2008), arm (Huisman et al. 2013) and cheek (Park et al. 2012), pinches, tickles (Furukawa et al. 2012), pats (Bonanni et al. 2006), squeezes (Rantala et al. 2013), thermal signals (Gooch and Watts 2010; Suhonen et al. 2012a,b), massages (Chung et al. 2009), and intimate sexual touches (Solon 2015).

In addition to direct mediation, there is also an option to use indirect ways, for instance, through avatars in a virtual world. Devices like a haptic-jacket system can enhance the communication between users of virtual worlds such as Second Life by enabling the exchange of touch cues resembling encouraging pats and comforting hugs between users and their respective avatars (Hossain et al. 2011). The Huggable is a semi-autonomous robotic teddy bear equipped with somatic sensors, intended to facilitate affective haptic communication between two people (Lee et al. 2009) through a tangible rather than a virtual interface. Using these systems, people can not only exchange messages but also emotionally and physically feel the social presence of the communication partner (Tsetserukou and Neviarouskaya 2010).

The above examples can be considered demonstrations of the potential devices and applications and the richness of social touch. Although it appears that virtual interfaces can effectively transmit emotion even with touch cues that are extremely degraded (e.g., a handshake that is lacking grip, temperature, dryness, and texture: Bailenson et al. 2007), the field lacks rigorous validation and systematic exploration of the critical parameters. The few exceptions are the work by Smith and MacLean (2007) and by Salminen et al. (2008). Smith and MacLean performed an extensive study into the possibilities and the design space of an interpersonal haptic link and concluded that emotion can indeed be communicated through this medium. Salminen et al. (2008) developed a friction-based horizontally rotating fingertip stimulator to investigate emotional experiences and behavioral responses to haptic stimulation and showed that people can rate these kind of stimuli as less or more unpleasant, arousing, avoidable, and dominating.

Remote Collaboration Between Groups

Collaborative virtual environments are increasingly used for distance education [e.g., Mikropoulos and Natsis (2011)], training simulations [e.g., Dev et al. (2007) and Flowers and Aggarwal (2014)], therapy treatments (Bohil et al. 2011), and for social interaction venues (McCall and Blascovich 2009). It has been shown that adding haptic feedback to the interaction between users of these environments significantly increases their perceived social presence (Basdogan et al. 2000; Sallnäs 2010).

Another recent development is telepresence robots that enable users to physically interact with geographically remote persons and environments. Their ultimate goal is to provide users with the illusion of a physical presence in remote places. Telepresence robots combine physical and remote presence and have a wide range of potential social applications like remote embodied teleconferencing and teaching, visiting or monitoring elderly in care centers, and making patient rounds in medical facilities (Kristofferson et al. 2013). To achieve an illusion of telepresence, the robot should be able to reciprocate the user's behavior and to

provide the user with real-time multisensory feedback. As far as we are aware of, systems including the sense of touch have not been described yet.

Reactions to Mediated Touch at a Physiological, Behavioral, and Social Level

Although the field generally lacks serious validation studies, there is mounting evidence that people use, experience, and react to direct and mediated social touch in similar ways Bailenson and Yee (2007), at the physiological, psychological, behavioral, and social level.

At a physiological and psychological level, mediated affective touch on the forearm can reduce heart rate of participants that experienced a sad event (Cabibihan et al. 2012). Mediated touch affects the quality of a shared experience and increases the intimacy felt toward the other person (Takahashi et al. 2011). Stimulation of someone's hand through mediated touch can modulate the quality of a remotely shared experience (e.g., the hilarity of a movie) and increase sympathy for the communication partner (Takahashi et al. 2011). In a storytelling paradigm, participants experienced a significantly higher degree of connectedness with the storyteller when the speech was accompanied by remotely administered squeezes in the upper arm (Wang et al. 2012). Additional evidence for the potential effects of mediated touch are found in the fact that hugging a robot medium while talking increases affective feelings and attraction toward a conversation partner (Kuwamura et al. 2013; Nakanishi et al. 2013). Participants receiving tactile facial stimulation experienced a stranger receiving similar stimulation to be closer, more positive and more similar to themselves when they were provided with synchronous visual feedback (Paladino et al. 2010).

At a behavioral level, the most important observation is that the effect of a mediated touch on people's pro-social behavior is similar to that of a real touch. According to Haans and IJsselstein (2009a), a virtual Midas touch has effects in the same order of magnitude as a real Midas touch. At the social level, the use of mediated touch is only considered appropriate as a means of communication between people in close personal relationships (Rantala et al. 2013), and the mere fact that two people are willing to touch implies an element of trust and mutual understanding (Collier 1985). The interpretation of mediated touch depends on the type of interrelationship between sender and receiver (Rantala et al. 2013), similar to direct touch (Coan et al. 2006; Thompson and Hampton 2011) and like direct touch, mediated touch communication between strangers can cause discomfort (Smith and MacLean 2007).

Social Touch Generated by ICT Systems

The previous chapter dealt with devices that enable interpersonal social touch communication, i.e., a situation in which the touch signals are generated and interpreted by human users and only mediated through information and communication technology. One step beyond this is to include social touch in the communication between a user and a virtual entity. This implies three additional challenges: the generation of social touch signals from system to user, the interpretation of social touch signals

provided by the user to the system, and closing the loop between these signals.

Generating Social Touch Signals

Lemmens et al. (2009) tested tactile jackets (and later blankets) to increase emotional experiences while watching movies and reported quite strong effects of well-designed vibration patterns. Dijk et al. (2013) developed a dance vest for deaf teenagers. This vest included an algorithm that translated music into vibration patterns presented through the vest. Although not generated by a social entity, experiencing music has a substantial emotional part as did the automatically generated vibration patterns.

Beyond the scripted and one-way social touch cues employed in the examples above, human-computer interaction applications increasingly deploy intelligent agents to support the social aspects of the interaction (Nijholt 2014). Social agents are used to communicate, express, and perceive emotions, maintain social relationships, interpret natural cues, and develop social competencies (Fong et al. 2003; Li et al. 2011). Empathic communication in general may serve to establish and improve affective relations with social agents (Bickmore and Picard 2005), and may be considered as a fundamental requirement for social agents that are designed to function as social companions and therapists (Breazeal 2011). Initial studies have shown that human interaction with social robots can indeed have therapeutic value (Kanamori et al. 2003; Wada and Shibata 2007; Robinson et al. 2013). These agents typically use facial expressions, gesture, and speech to convey affective cues to the user. Social agents (either physically embodied as, e.g., robots or represented as on-screen virtual agents) may also use (mediated) touch technology to communicate with humans (Huisman et al. 2014a). In this case, the touch cue is not only mediated but also generated and interpreted by an electronic system instead of a human.

The physical embodiment of robots gives them a direct capability to touch users, while avatars may use the technology designed for other HCI or mediated social touch applications to virtually touch their user. Several devices have been proposed that enable haptic interaction with virtual characters (Hossain et al. 2011; Rahman and El Saddik 2011; Huisman et al. 2014a). Only few studies investigated autonomous systems that touch users for affective or therapeutic purposes (Chen et al. 2011), or that use touch to communicate the affective state of artificial creatures to their users (Yohanan and MacLean 2012).

Recognizing and Interpreting Social Touch Signals

Communication implies a two-way interaction and social robots and avatars should therefore not only be able to generate but also to recognize affectionate touches. For instance, robotic affective responses to touch may contribute to people's quality of life (Cooney et al. 2014). Touch capability is not only "nice to have" but may even be a necessity: people expect social interaction with embodied social agents to the extent that physical embodiment without tactile interaction results in a negative appraisal of the robot (Lee et al. 2006). In a recent study on the suitability of social robots for the wellbeing of the elderly, all participants expressed their wish for the robot to feel pleasant to hold or stroke and to

respond to touch (Hutson et al. 2011). The well-known example of the pet seal Paro (Wada et al. 2010) shows how powerful a simple device can be in evoking social touches. Paro responds to being touched but does neither interpret social touch nor produce touch. Similar effects are reported for touching a humanoid robot on the shoulder: just being able to touch already significantly increases trust toward the robot (Dougherty and Scharfe 2011).

Automatic recognition and interpretation of the affective content of human originated social touch is essential to support this interaction (Argall and Billard 2010). Different approaches to equipping robots with a sense of touch include covering them with an artificial skin that simulates the human somatosensory systems (Dahiya et al. 2010) or the use of fully embodied robots covered with a range of different (e.g., temperature, proximity, pressure) sensors (Stiehl et al. 2005). To fully capture a social touch requires sensors that go beyond those used in the more advanced area of haptics and that primarily involve discriminative touch (e.g., contact, pressure, resistance). At least sensors for temperature and soft, stroking touch should be included to capture important parameters of social touch. However, just equipping a system (robot, avatar, or interface) with touch sensors is not sufficient to enable affective haptic interaction. A system can only appreciate and respond to affective touch in a natural way when it is able (a) to determine where the touch was applied, (b) to assess what kind of tactile stimulation was applied, and (c) to appraise the affective quality of the touch (Nguyen et al. 2007). While video- and audio-based affect recognition have been widely investigated (Calvo and D'Mello 2010), there have only been a few studies on touch-based affect recognition. The results of these preliminary studies indicate that affect recognition based on tactile interaction between humans and robots is comparable to that between humans (Naya et al. 1999; Cooney et al. 2012; Altun and MacLean 2014; Jung et al. 2014; van Wingerden et al. 2014).

Research on capturing emotions from touch input to a computer system (i.e., not in a social context) confirms the potential of the touch modality (Zacharatos et al. 2014). Several research groups worked on capturing emotions from traditional computer input devices like mouse and keyboard based on the assumption that a user's emotional state affects the motor output system. A general finding is that typing speed correlates to valence with a decrease in typing speed for negative valence and increased speed for positive valence compared to typing speed in neutral emotional state (Tsihrintzis et al. 2008; Khanna and Sasikumar 2010). A more informative system includes the force pattern of the key strokes. Using this information, very high-accuracy rates (>90%) are reported (Lv et al. 2008) for categorizing six emotional states (neutral, anger, fear, happiness, sadness, and surprise). This technique requires force sensitive keyboards, which are not widely available. Touch screens are used by an increasing number of people and offer much richer interaction parameters than keystrokes such as scrolling, tapping, or stroking. Recent work by Gao et al. (2012) showed that in a particular game played on the iPod, touch inputs like stroke length, pressure, and speed were important features related to a participant's verbal description of the emotional experience during the game. Using a linear SVM, classification performance reached 77% for four emotional classes

(excited, relaxed, frustrated, and bored), close to 90% for two levels of arousal, and close to 85% for two levels of valence.

Closing the Loop

A robot that has the ability to “feel,” “understand,” and “respond” to touch in a human-like way will be capable of more intuitive and meaningful interaction with humans. Currently, artificial entities that include touch capabilities either produce or interpret social touch, but not both. However, both are required to close the loop and come to real, bidirectional interaction. The latter may require strict adherence to, for instance, timing and immediacy; a handshake in which the partners are out-of-phase can be very awkward. And as Cranny-Francis (2011) states, violating the tactile regime may result in being rejected as alien and may seriously offend others.

Reactions to Touching Robots and Avatars at a Physiological, Behavioral, and Social Level

Although there are still very few studies in this field, and there has been hardly any real formal evaluation, the first results of touch interactions with artificial entities appear promising. For instance, people experience robots that interact by touch as less machine-like (Cramer et al. 2009). Yohanan and colleagues (Yohanan et al. 2005; Yohanan and MacLean 2012) designed several haptic creatures to study a robot's communication of emotional state and concluded that participants experienced a broader range of affect when haptic renderings were applied. Basori et al. (2009) showed the feasibility of using vibration in combination with sound and facial expression in avatars to communicate emotion strength. Touch also assists in building a relationship with social actors: hand squeezes (delivered through an airbladder) can improve the relation with a virtual agent (Bickmore et al. 2010). Artificial hands equipped with synthetic skins can potentially replicate not only the biomechanical behavior but also the warmth (the “feel”) of the human hand (Cabibihan et al. 2009, 2010, 2011). Users perceived a higher degree of friendship and social presence when interacting with a zoomorphic social robot with a warmer skin (Park and Lee 2014). Recent experiments indicate that the warmth of a robotic hand mediating social touch contributed significantly to the feeling of social presence (Nakanishi et al. 2014) and holding a warm robot hand increased feelings of friendship and trust toward a robot (Nie et al. 2012).

Kotranza and colleagues (Kotranza and Lok 2008; Kotranza et al. 2009) describe a virtual patient as a medical student's training tool that is able to be touched and to touch back. These touch-enabled virtual patients were treated more like real humans than virtual patients without touch capabilities (students expressed more empathy and used touch more frequently to comfort and reassure the virtual patient). The authors concluded that by adding haptic interaction to the virtual patient, the bandwidth of the student-virtual patient communication increases and approaches that of human-human communication. In a study on the interaction between toddlers and a small humanoid robot, Tanaka et al. (2007) found that social connectedness correlated with the amount of touch between the child and robot. In a study where participants were asked to brush off “dirt” from either virtual objects or virtual humans, they touched virtual humans with

less force than non-human objects, and they touched the face of a virtual human with less force than the torso, while male virtual humans were touched with more force than female virtual humans (Bailenson and Yee 2008). Huisman et al. (2014b) performed a study in which participants played a collaborative augmented reality game together with two virtual agents, visible in the same augmented reality space. During interaction, one of the virtual agents touched the user on the arm by means of a vibrotactile display. They found that the touching virtual agent was rated higher on affective adjectives than the non-touching agent. Finally, Nakagawa et al. (2011) created a situation in which a robot requested participants to perform a repetitive monotonous task. This request was accompanied by an active touch, a passive touch, or no touch. The result showed that the active touch increased people's motivation to continue performing the monotonous task. This confirms the earlier finding of Haans and IJsselsteijn (2009a) that the effect of the virtual Midas touch is in the same order of magnitude as the real Midas touch effect.

Research Topics

Mediated social touch is a relatively young field of research that has the potential to substantially enrich human–human and human–system interaction. Although it is still not clear to what extent mediated touch can reproduce real touch, converging evidence seems to show that mediated touch shares important effects with real touch. However, many studies have an anecdotal character without solid and/or generalizable conclusions and the key studies in this field have not been replicated yet. This does not necessarily mean that the results are erroneous but it indicates that the field has not matured enough and may suffer from a publication bias. We believe that we need advancements in the following four areas for the field to mature: building an overarching framework, developing social touch basic building blocks, improving current research methodologies, and solving specific ICT challenges.

Framework

The human skin in itself is a complex organ able to process many different stimulus dimensions such as pressure, vibration, stretch, and temperature (van Erp 2007). “Social touch” is what the brain makes of these stimulus characteristics (sensations) taking into account personality, previous experiences, social conventions, the context, the object or person providing the touch, and probably many more factors. The scientific domains involved in social touch each have interesting research questions and answering them helps the understanding of (real life or mediated) social touch. In addition, we need an overarching framework to link the results across disciplines, to foster multidisciplinary research, and to encourage the transition from exploratory research to hypothesis driven research.

Neuroscience

The recent finding that there exists a distinct somatotopic mapping between tactile sensations and different emotional feelings (Nummenmaa et al. 2013; Walker and McGlone 2015) suggests that it may also be of interest to determine a map of our responsiveness to interpersonal (mediated) touch across the skin surface (Gallace and Spence 2010). The availability of such a map

may stimulate the further development of mediated social touch devices. Another research topic is the presumed close link between social touch and emotions and the potential underlying neurophysiological mechanisms, i.e., the connection between social touch and the emotional brain.

Multisensory and Contextual Cues

The meaning and appreciation of touch critically depend on its context (Collier 1985; Camps et al. 2012), such as the relation between conversation partners (Burgoon et al. 1992; Thompson and Hampton 2011), the body location of the touch (Nguyen et al. 1975), and the communication partner's culture (McDaniel and Andersen 1998). There is no one-to-one correspondence between a touch and its meaning (Jones and Yarbrough 1985). Hence, the touch channel should be coupled with other sensory channels to clarify its meaning (Wang and Quek 2010). An important research question is which multisensory and contextual cues are critical. Direct (i.e., unmediated) touch is usually a multisensory experience: during interpersonal touch, we typically experience not only tactile stimulation but also changes in warmth along with verbal and non-verbal visual, auditory, and olfactory signals. Non-verbal cues (when people both see, hear, feel, and possibly smell their interaction partner performing the touching) may render mediated haptic technology more transparent, thereby increasing perceived social presence and enhancing the convincingness or immediacy of social touch (Haans and IJsselsteijn 2009b, 2010). Also, since the sight of touch activates brain regions involved in somatosensory processing [Rolls (2010); even watching a videotaped version: Walker and McGlone (2015)], the addition of visual feedback may enhance the associated haptic experience. Another strong cue for physical presence is body warmth. In human social interaction, physical temperature also plays an important role in sending interpersonal warmth (trust) information. Thermal stimuli may therefore serve as a proxy for social presence and stimulate the establishment of social relationships (IJzerman and Semin 2010).

In addition to these bottom-up, stimulus driven aspects, top-down factors like expectations/beliefs of the receiver should be accounted for (e.g., beliefs about the intent of the interaction partner, familiarity with the partner, affordances of a physically embodied agent, etc.) since they shape the perceived meaning of touch (Burgoon and Walther 1990; Gallace and Spence 2010; Suhonen et al. 2012b).

Social and Cultural

Social touch has a strong (unwritten) etiquette (Cranny-Francis 2011). Important questions are how to develop a touch etiquette for mediated touch and for social agents that can touch (van Erp and Toet 2013), and how to incorporate social, cultural, and individual differences with respect to acceptance and meaning of a mediated or social agent's touch. Individual differences may include gender, attitude toward robots, and technology and touch receptivity [the (dis-)liking of being touched, Bickmore et al. 2010]. An initial set of guidelines for this etiquette is given by van Erp and Toet (2013). In addition, we should consider possible ethical implications of the technology, ranging from affecting people's behavior without them being aware of it to the threat of physical abuse “at a distance.”

Social Touch Building Blocks

Gallace and Spence (2010) noted that even the most advanced devices will not be able to deliver something that can approximate realistic interpersonal touch if we do not know exactly what needs to be communicated and how to communicate it. Our touch capabilities are very complex, and like mediated vision and audition, mediated touch will always be degraded compared to real touch. The question is how this degradation affects the effects aimed for. *A priori*, mediated haptic communication should closely resemble non-mediated communication in order to be intuitively processed without introducing ambiguity or increasing the cognitive load (Rantala et al. 2011). However, the results discussed in this paper [e.g., Bailenson et al. (2007), Smith and MacLean (2007), Haans and IJsselsteijn (2009a), Giannopoulos et al. (2011), and Rantala et al. (2013)] indicate that social touch is quite robust to degradations and it may not be necessary to mediate all physical parameters accurately or at all.

However, it is currently not even clear how we can haptically represent valence and arousal, let alone that we have robust knowledge on which parameters of the rich and complex touch characteristics are crucial in relation to the intended effects. Ideally, we have a set of building blocks of social touch that can be applied and combined depending on the situation.

Methodology

Not uncommon for research in the embryonic stage, mediated social touch research is going through a phase of haphazard, anecdotal studies demonstrating the concept and its' potential. To mature, the field needs rigorous replication and methodological well-designed studies and protocols. The multidisciplinary nature of the field adds to the diversity in research approaches.

Controlled Studies

Only few studies have actually investigated mediated affect conveyance, and compared mediated with unmediated touch. Although it appears that mediated social touch can indeed to some extent convey emotions (Bailenson et al. 2007) and induce pro-social behavior [e.g., the Midas effect; Haans and IJsselsteijn (2009a)], it is still not known to what extent it can also elicit strong affective experiences (Haans and IJsselsteijn 2006) and how this all compares to real touch or other control conditions.

Protocols

Previous studies on mediated haptic interpersonal communication mainly investigated the communication of deliberately performed (instructed) rather than naturally occurring emotions (Bailenson et al. 2007; Smith and MacLean 2007; Rantala et al. 2013). Although this protocol is very time efficient, it relies heavily on participants' ability to spontaneously generate social touches with, for instance, a specific emotional value. This is comparable to the research domain of facial expression where often trained actors are used to produce expressions on demand. One may consider training people in producing social touches on demand or employ a protocol (scenario) that naturally evokes specific social signals rather than instruct naïve participants to produce them.

Effect Measures

Social touch can evoke effects at many different levels in the receiver: physiological, psychological, behavioral, and social, and it is likely that effects at these different levels also interact. For instance, (social) presence and emotions can reciprocally reinforce each other. Currently, a broad range of effect measures is applied, which makes it difficult to compare results, assess interactions between levels, and combine experimental results into an integrated perspective. This pleads for setting a uniform set of validated and standardized measures that covers the different levels and that is robust and sensitive to the hypothesized effects of social touch. This set could include basic physiological measures known to vary with emotional experience [e.g., heart rate variability and skin conductance; Hogervorst et al. 2014]; psychological and social measures reflecting trust, proximity, togetherness, and social presence (IJsselsteijn et al. 2003; Van Bel et al. 2008; van Bel et al. 2009), and behavioral measures, e.g., quantifying compliance and performance. Please note though that each set of measures will have its own pitfalls. For instance, see Brouwer et al. (2015) for a critical reflection on the use of neurophysiological measures to assess cognitive or mental state, and Bailenson and Yee (2008) on the use of self-report questionnaires.

Specific ICT Challenges

Enabling ICT mediated, generated, and/or interpreted social touch requires specific ICT knowledge and technology. We consider the following issues as most prominent.

Understanding Social Touches

With a few exceptions, mediated social touch studies are restricted to producing a social touch and investigate its effects on a user. To use social touch in interaction means that the system should not only be able to generate social touches but also to receive and understand social touches provided by human users. Taken the richness of human touch into account, this is not trivial. We may currently not even have the necessary sensor suite to capture a social touch adequately, including parameters like sheer and tangential forces, compliance, temperature, skin stretch, etc. After adequate capturing, algorithms should determine the social appraisal of the touch. Currently, the first attempts to capture social touches with different emotional values on a single body location (e.g., the arm) and to use computer algorithms to classify them are undertaken (van Wingerden et al. 2014).

Context Aware Computing and Social Signal Processing

The meaning of a social touch is highly dependent on the accompanying verbal and non-verbal signals of the sender and the context in which the touch is applied. An ICT system involved in social touch interaction should take the relevant parameters into account, both in generating touch and in interpreting touch. To understand and manage social signals of a person, the system is communicating with is the main challenge in the – in itself relatively young – field of social signal processing (Vinciarelli et al. 2008). Context aware (Schilit et al. 1994) implies that the system can sense its environment and reason about it in the context of social touch.

Congruency in Time, Space, and Semantics

As with most multimodal interactions, congruency of the signals in space, time, and meaning is of eminent importance. For instance, touches should be congruent with other (mediated) display modalities (visual, auditory, olfactory) to communicate the intended meaning. In addition, congruency in time and space between, for instance, a seen gesture and a resulting haptic sensation is required to support a common interaction metaphor based on real touch. It has been shown that combining mediated social touch with morphologically congruent imagery enhances perceived social presence, whereas incongruent imagery results in lower degrees of social presence (Haans and IJsselsteijn 2010).

Especially in closed-loop interaction (e.g., when holding or shaking hands), signals that are out of sync may severely degrade the interaction, thus requiring (near) real-time processing of touch and other social signals and generation of adequate social touches in reaction.

Enhancing Touch Cues

Social touch seems robust to degradations and mediated touch does not need to replicate all physical parameters accurately. The flipside of degradation is enhancement. Future research should investigate to what extent the affective quality of the mediated touch signals can be enhanced by the addition of other communication channels or by controlling specific touch parameters. Touch parameters do not necessarily have to be mediated one-to-one, but, for instance, temperature and force profiles may be either amplified or attenuated. The additional options mediation can provide to social touch have not been explored yet.

Conclusion

Social touch is of eminent importance in inter-human social communication and grounded in specific neurophysiological processing channels. Social touch can have effects at many levels including physiological (heart rate and hormone levels), psychological (trust in others), and sociological (pro-social behavior toward others).

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Current ICT advances like the embodiment of artificial entities, the development of advanced haptic and tactile display technologies and standards (van Erp et al. 2010, including initial guidelines for mediated social touch: van Erp and Toet 2013) enable the exploration of new ICT systems that employ this powerful communication option, for instance, to enhance communication between physically separated partners and increase trust in and compliance with artificial entities. There are two prerequisites to make these applications viable. First, inter-human social touch can be ICT mediated, and second, social touch can be ICT generated and understood, all without loss of effectiveness, efficiency, and user satisfaction.

In this paper, we show that there is converging evidence that both prerequisites can be met. Mediated social touch shows effects at aforementioned levels, and these effects resemble those of a real touch, even if the mediated touch is severely degraded. We also report the first indications that a social touch can be generated by an artificial entity, although the evidence base is still small. Moreover, the first steps are taken to develop algorithms to automatically classify social touches produced by the user.

Our review also shows that (mediated) social touch is an embryonic field relying for a large part on technology demonstrations with only a few systematic investigations. To advance the field, we believe the focus should be on the following four activities: developing an overarching framework (integrating neuroscience, computer science, and social and behavioral science), developing basic social touch building blocks (based on the critical social touch parameters), applying stricter research methodologies (use controlled studies, validated protocols, and standard effect measures), and realizing breakthroughs in ICT (classifying social touches, context aware computing, social signal processing, congruency, and enhancing touch cues).

When we are successful in managing these challenges at the crossroads of ICT and psychology, we believe that (mediated) social touch can improve our wellbeing and quality of life, can bridge the gap between real and virtual (social) worlds, and can make artificial entities more human-like.

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