Social Touch Technology: A Survey of Haptic Technology for Social Touch

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Abstract—This survey provides an overview of work on haptic technology for social touch. Social touch has been studied extensively in psychology and neuroscience. With the development of new technologies it is now possible to engage in social touch at a distance or engage in social touch with artificial social agents. Social touch research has inspired research into technology mediated social touch, and this line of research has found effects similar to actual social touch. The importance of haptic stimulus qualities, multimodal cues, and contextual factors in technology mediated social touch is discussed. This survey is concluded by reflecting on the current state of research into social touch technology, and providing suggestions for future research and applications.

Index Terms—Haptics and haptic interfaces; Social touch; Affective touch; Medaited social touch; Simulated social touch

1 Introduction

The way we interact with our digital devices, such as laptops, smart phones, and tablets is mainly through our visual and auditory senses. When we think of using our sense of touch in such interactions, images of clicking mouse buttons, and sliding our fingers over a glass display spring to mind. The field of haptics is concerned with investigating human-machine communication through the sense of touch [1], in interactions where we can not only use our sense of touch for input, but also receive computer generated touch output.

Research into haptics has mainly focussed on addressing the discriminative aspects of the human sense of touch. These discriminative aspects relate to the use of the human sense of touch as an exteroceptive organ, that can detect, discriminate, and identify stimuli outside the body in order to guide behavior [2]. Haptic interfaces can be used to provide information about the state of a system through the user's sense of touch in order to allow the user to make decisions based on this information [1][3]. Applications of such interfaces are found in remote operation, such as remote surgery [4], haptic navigation systems, for example for helicopter pilots [5], and haptic warning systems, such as lane departure warnings in cars [6].

Apart from its discriminative function, the human sense of touch also serves an important interoceptive, affective function [2]. Hedonic aspects of the human sense of touch are easily understood when thinking about unpleasant (e.g. the feeling of sandpaper on the skin), or painful sensations on the one hand, and pleasant sensations (e.g. the feeling of silk on the skin) or stimulation of erogenous zones on the other hand [7]. However, when we think of the most affect laden forms of touch, being touched by another person (not necessarily in a sexual way) is perhaps the most powerful affective signal. Touch occurring between two or more individuals in co-located space is often referred to as interpersonal, or social touch [8][9][10](see also [7, p.8] for a discussion on this relatively broad definition of social touch). Although it occurs less frequently than other social signals, such as facial expressions, the use of social touch is diverse, ranging form use during greetings, to showing affection and support [11], and social touch can profoundly influence social interactions [7]. For example, touch can lead to more favorable evaluations of the toucher [12], can serve a persuasive function [13], and can fulfill an important role in the regulation of physical and emotional wellbeing [14]. As the first sense to develop in the womb [15][16], touch is vital for the bonding between mother and child [17], and remains highly important in later social life [7].

From a technological point of view, haptic technology has the capability of emulating aspects of human touch, such as applying force or warmth. However, when such sensations are used in haptic interactions aimed at social communication, that is, using haptics for social touch, a whole new layer of complexity is added. The way any social touch is interpreted, is for example dependent on the type of touch [18], the body location it is applied to [19], as well as relational [20][21], cultural [22], and broader contextual factors [23].

The aim of this survey is to shed light on the complexities of using haptic technology for social touch. The use of haptic technology for social touch interactions is referred to here as social touch technology (STT). STT includes situations where human communication partners engage in social touch mediated through technology [8], as well as situations where humans interact with artificial social agents that have the capability of responding to, and/or applying social touches [24][25].

Note that the present survey differs from two previously published surveys on related topics [8][25]. First, the present survey should be seen as an update to the survey on mediated social touch by Haans and Ijsselsteijn [8] from 2006, in that here, an updated list of prototypes, and new empirical research on mediated social touch are included. The present survey is also an extension as it also includes a discussion of

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simulated social touch. The aim of the present survey differs from the overview provided by Van Erp and Toet [25], in that the focus here is less on underlying psychological factors, and more on the types of touch used in social touch, as well as the types of haptic feedback used in STT. Both these points should be of particular interest to those working on social interactions through haptic technology.

The literature featured in this survey was collected on a continuous basis as part of ongoing research into STT from 2011 until 2016. Google Scholar was used as the main search method, but relevant specialized databases, including the ACM Digital Library, SpringerLink, and IEEE Xplore Digital Library, were also used. The primary search terms used in the initial phase of collecting literature were combinations of the following: touch; tactile; haptic; social; affect. The collection of literature yielded 936 papers covering diverse topics. Literature was included in the present survey based on common themes that could be identified in this collection process. These themes form the structure of the present survey, beginning with a discussion of the neurophysiology of human touch to give insights into how the sense of touch might be best addressed by haptic technology for social interactions. Next, effects of actual human-human social touch in social interactions will be discussed to allow for comparisons to be made with effects of STT. The focus of this survey will be an extensive overview of work on social touch mediated through haptic technology, both in human-human, and human-agent interactions. This survey will conclude by reflecting on the current state of STT research and by providing directions for future research.

2 The human sense of touch

In this section the distinction between discriminative and affective touch is outlined, and it is discussed what this distinction means for STT.

2.1 Discriminative touch

An important function of the human sense of touch is to obtain information about the external world. Functionally, a distinction can be made between the kinesthetic and cutaneous senses [26][27]. The kinesthetic sense provides information about the position of limbs in time and space, and information about muscular effort to the central nervous system in order to guide body movement [27]. Force-feedback type haptic interfaces, exerting forces on the limbs of a user, address the kinesthetic sense, though receptors in the skin are also stimulated. The cutaneous sense provides the central nervous system with information from a range of different receptors found in the skin. For example, vibrotactile actuators can stimulate specific types of mechanoreceptors (i.e. receptors that detect skin deformation) that are sensitive to certain vibration frequencies. A large body of work (see [28] for a review) has focussed on cutaneous receptors in the glabrous skin (i.e. hairless skin) found in the hand and fingers. Particularly the fingers contain a high density of low-threshold mechanoreceptors with fast conducting afferent nerves (i.e. nerve carrying information to the central nervous system) [2][28]. The high density of fast conducting mechanoreceptors makes the fingers and hands ideal for discriminative touch, and allows the fingers to, for example, detect the textures of an object [29].

2.2 Affective touch and the social touch hypothesis

The neurophysiology underlying discriminative touch is relatively well understood in terms of receptors, pathways to the brain, and perception [30]. This knowledge of discriminative touch has helped advance research into haptics, and the design of haptic interfaces [1][3]. However, researchers have only recently begun to unravel the neurophysiology of a secondary touch system, hypothesized to underlie social and affective touch [31][32][33].

The hairy skin, which covers most of the human body, has a lower density of fast conducting receptors than the hand and fingers [2][34]. However, only the hairy skin is innervated by a class of low threshold, unmyelinated (thus slow conducting) C Tactile (CT) afferents [35]. CT afferents offer poor spatial and temporal resolution, and are therefore not well suited for discriminative touch [32][34]. It has been found that CT afferents respond particularly strongly to gentle, stroking touches with firing rates following an inverted U-curve shape as a function of stroking velocity, and peaking at about 3cm/s [36]. Moreover, subjective ratings of the pleasantness of such touches follow a similar inverted U-curve shape, with stroking stimuli rated the most pleasant at a velocity of 3cm/s [34][36][37][38]. In addition, CT afferents project mainly to the insula, an area of the brain implicated in processing affect, whereas receptors for discriminative touch mainly project to the somatosensory cortices [2][32][34]. These findings have lead researchers to propose the social touch hypothesis [32][33], which states that CT afferents might serve as a "filter", that operates in conjunction with other mechanoreceptors (i.e. those for discriminative touch) in order to help determine if a certain touch has social relevance or not [32][33]. This hypothesis is supported by the notion that caressing touches to which CT afferents are sensitive, are particularly pertinent in affiliative interactions between humans [32][34][36][38]. This may be especially the case between mothers and infants [15][17][39]. What is more, CT afferents respond most vigorously to stroking touches applied by a stimulus at skin temperature [40].

Thus, there is a dedicated pathway that underlies affective touch, and that is distinct from discriminative touch. Nevertheless it should be appreciated that in social touch interactions, both discriminative and affective touch systems play a role [2]. Many different types of touch are used in social touch interactions that do not involve stroking of the skin, but involve CT non-optimal touches (e.g. squeezing), such as during a handshake [11][41]. What is more, shaking hands, as well as other types of touch, mainly stimulate the glabrous skin which lacks CT afferents. Nevertheless such stimulation can produce a pleasant percept [42]. In these situations, the physical aspects of a social touch are detected primarily through receptors important for discriminative touch.

Processing of pleasant touch through the affective touch CT pathway is considered an innate non-learned process [2], yet it should be noted that the perception of pleasant stroking touches can be modulated by cognitive processes,

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such as interpretation of verbal descriptors [43], or attribution of the touch to a male or female [44]. Moreover, Kress et al. [18] found that stroking with a human hand compared to with a velvet stick resulted in larger responses in both sensory and affect related brain regions, and higher subjective pleasantness ratings. This difference is possibly due to a combination of perceptual differences (i.e. a human hand actually feels different from a velvet stick) and cognitive and emotional correlates of being touched by another person [18]. In addition, CT optimal stroking touches observed from a video can result in similar activation of the posterior insula as received CT optimal stroking touches, but only when the observed touch occurs in a social setting [45]. Self reports of pleasantness also showed similarities between felt and observed CT optimal touch, thus it seems that visual cues of both the type of touch as well as the social setting influence affective touch perception [45]. Nevertheless, Willemse et al. [46] found that pleasantness ratings of observed stroking touch to a human arm, showed a similar response pattern for stroking with an actual human hand, mannequin arm, robot arm, and plastic tube. This would suggest that the interpretation of the social setting may be more dependent on the recipient than on the stimulus that applies the touch.

In the present survey social touch is considered to involve both discriminative and affective touch systems working in tandem. The affective touch system may be especially relevant for the innate processing of social touch, but only for a small subset of touches (i.e. stroking touches). A much broader range of social touches is detected through the discriminative touch system, but a more cognitively involved process is required to derive social and affective meaning from such touches (see also [2]). In the following sections we will discuss social touch interactions that involve both discriminative and affective touch systems, and we will highlight important factors that influence the perception of social touches through both systems. We start by outlining how social touch can affect the toucher and recipient of the touch in the next section.

3 Effects of social touch

In order to get a more detailed picture of how haptic interfaces might be used for social touch in all its varieties, it is important to first consider what effects unmediated human-human social touch can have. In this section we will discuss effects of social touch on four relevant topics that have been identified in the literature, namely: physical and emotional wellbeing, attachment and bonding, attitude and behavior change, and communication of affect.

3.1 Physical and emotional wellbeing

Social touch is considered important for the proper development of infants, as a lack of touch in the early stages of an infant's life can have negative consequences for the infant's wellbeing later on (for a review see [47]). Observations from orphans deprived of social and sensory stimulation, revealed these children to be lacking in cognitive, emotional, and social development [48][49][50]. While it is difficult to isolate the effects of a lack of touch from those of general deprivation, some argue that the lack of social touch contributes strongly to negative effects on infant development found in orphans [15][16]. Indeed, caring maternal touch has a positive impact on neurological development of low-birthweight infants, resulting in greater visual-motor skill development later on [51]. Touch, either used in combination with other stimuli [52] or used on its own [53] has been found to reduce physical discomfort and pain in infants undergoing painful medical procedures. Maternal touch has positive effects on infants' stress response and recovery from stress, measured as cardiac vagal tone and cortisol (a stress hormone) levels [54], and may be beneficial for the mother too [54], as a co-regulation process with the infant takes place [55]. It is worthwhile to note here that massaging, a more intense form of touch, may offer additional benefits to infants, (for a review see [56]), and may also help children suffering from afflictions in the autism spectrum disorder (ASD) [57], who are typically aversive to being touched [15][58][59].

Positive effects of social touch on physical and emotional wellbeing are also pertinent in later life, especially for individuals in romantic relationships. Holding one's partner's hand, rather than holding an object or stranger's hand, when receiving a painful stimulus results in lower pain ratings [60]. Partner contact in the form of hand holding, hugging, or massaging prior to a stressful task, results in lower stress responses measured through cortisol levels, blood pressure and heart rate [61][62]. Such effects of touch on stress responses are stronger for touch between spouses, as compared to receiving touch from a stranger, and may be influenced by marital quality [63]. Moreover, short-term effects of partner contact may be stronger for those individuals who receive more partner hugs in general [64]. Higher levels of oxytocin (a "social bonding" hormone) may be a predictor of such frequent contact, and potentially mediate short-term positive effects of partner contact [64]. Frequent partner contact over longer periods of time is related to positive affect and psychological wellbeing [65], and is related to a lower risk of infection with the common cold virus [66].

Social touch by a stranger can also lower a person's heart rate [67], and such effects can be beneficial for stress reduction in health care settings. Touch by a nurse prior to a patient's surgery, can decrease a patient's stress level and positively influence the patient's affective state [68]. Though note that such effects were only found for female-female touch, while touch had a negative effect on male patients [68]. The use of social touch as a form of therapy can have positive effects on the reduction of stress in patients in intensive care units [69]. Massage therapy has been found to be both more successful in the release of pain, as well as the improvement of the mood of cancer patients, compared to simple touch [70]. For a complete overview of the effects of massage therapy the reader is referred to [71].

3.2 Attachment and bonding

Attachment theory states that in times of distress, an infant will seek close proximity to its caregiver (most often the mother)[72][73][74]. Physical contact in this regard serves as an important signal for safety and security [74]. The

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attachment relationship is formed by the infant repeatedly seeking contact with the mother, as well as the manner in which the mother responds to the physical contact [72][75]. Nurturing touch, rather than the frequency of touch per se, has been found to be important for the forming of secure attachment relationships for low-birthweight infants [74]. Still, children who are less frequently touched by their parents, score higher on reports of current depression and show less secure attachment styles in later life [76].

Conversely, a person's attachment style can predict their feelings towards touch in both romantic, and parent-child relationships [77]. Individuals with a less secure attachment style have been found to have more negative feelings towards cuddling in both types of relationships [77]. Miller et al. [78] studied college student's responses to images described as depicting their partners engaged in touch of different intimacy levels with an opposite-sex friend. More intimate types of touch (i.e. touch to the torso) resulted in stronger feelings of jealousy overall, but especially for female participants, and individuals with less secure attachment styles.

The concept of attachment is closely related to other concepts relating to interpersonal relationships, such as love and intimacy [79], and attachment theory has long since been recognized as a framework for explaining adult romantic attachment [80]. Non-sexual physical affection is positively correlated with relationship and partner satisfaction, and can help with conflict resolution within romantic couples [81]. The bonding aspect of social touch within couples, may be mediated by the release of oxytocin that results from being touched [82][83][84]. Oxytocin is a hormone that has been implicated in bonding behavior of mammals, and is released during physical contact, such as grooming [85]. Light et al. [64] not only found health benefits (in the form of lower blood pressure) of frequent partner hugs, but also an increase in oxytocin levels in women. This suggests that social touch, possibly mediated by the release of oxytocin, aids couples in the forming of lasting social (romantic) bonds [86].

3.3 Attitude and behavior change

Social touch has the potential to influence the attitude and behavior of the person receiving the touch. A brief touch to the hand, arm, or shoulder can positively influence attitudes towards the toucher [12][20][87][88], the affective state of the recipient of the touch [87], and attitudes towards the setting in which the touch takes place [87][88].

Besides resulting in changes in the attitude of the recipient of a touch, social touch can also impact the behavior of the recipient. An oft studied phenomenon in social touch research is the Midas touch effect [13] which describes the positive effects of social touch on pro-social behavior. This effect has been demonstrated in numerous ecologically valid settings, with a diverse range of observed pro-social behaviors. The Midas touch effect can result in increases in willingness to return lost money [89], increases in restaurant tipping after a touch by a waitress [13][88][90], enhanced compliance to menu item suggestions in a restaurant after a touch by a waiter or waitress [91], and influence purchase decisions [88]. Other findings include that a brief touch to the forearm increases the chances that people will spontaneously help to pick up dropped items [92], increases the chances that students will volunteer to write down an answer on the blackboard during class [93], increases the time that participants are willing to spend on a repetitive task, such as filling out bogus personality questionnaire items [94], and increases the likelihood people will give their opinion on difficult social issues [95]. In health care settings, research has shown that a touch by a medical practitioner increases the chances that a patient will adhere to their medication [96], and touch by caregivers in an elderly home can result in increases in calorie and protein intake by the elderly [97].

The Midas touch effect may be influenced by characteristics of the toucher and the person who is touched. Touch by physically more attractive people has a stronger positive effect on pro-social behavior [20][88]. In addition, touch by a female seems to have a stronger positive impact on pro-social behavior than touch by a male, for both male and female recipients [98][99]. Moreover, effects of touch on pro-social behavior may depend on the type of request. Touch may especially affect compliance for moderate requests, such as filling out a survey [99], but may have little effect for very easy (signing a petition) [99] or very difficult (signing up to become a blood donor) [100] requests. Finally, touch can also negatively impact pro-social behavior, when it is applied in a competitive rather than supportive context [23].

Interestingly the Midas touch effect occurs after very brief (<1 sec.) contact, and occurs whether the recipient of the touch is aware of being touched or not [101]. It is currently not clear what accounts for the Midas touch effect exactly. One suggestion is that the touch is interpreted by the receiver as a signal that the toucher likes and trusts him/her, which is reciprocated by the receiver in the form of pro-social behavior [9]. Another explanation is that touch serves as a signal for power and status differences, resulting in the recipient of a touch to be more compliant [23][94]. However, this offers little explanation for findings where enhanced pro-social behavior was found for participants unaware of being touched [101]. Possibly, increases in oxytocin levels as a result of being touched, support cooperative behavior [102]. Finally, some argue that Midas touch studies suffer from confederate bias [89][103][104], where the confederate that applies the touch also, unwillingly, adjusts other social cues such as their gaze [89], which may impact pro-social behavior.

3.4 Communication of affect

Touch can directly influence affect through erogenous zones and nociceptors (i.e. pain)[7], and can re-enforce emotional displays from other modalities, such as facial expressions in mother-infant interactions [105]. The body location to which such mother-infant touch is applied can elicit affective responses in the infant, such as negative responses to being touched on the abdomen [106]. Furthermore, in mother-infant interactions, stroking touches have been found to elicit more positive responses from infants, than either poking or tickling touches [107].

Touch does not only communicate positive or negative affective states, but the nature of the touch itself can be used to communicate discrete emotions. In a study by Hertenstein et al. [41] participants were able to communicate, by only touching the forearm of another person, a number of emotions at above chance level, with recognition rates similar to those found in research into facial expressions. Specific touches were related to the communication of certain emotions. For example, anger was communicated by hitting, squeezing, or trembling, whereas love was mostly communicated by stroking, finger interlocking, and rubbing [41]. Moreover, when the entire body was available to touch, additional emotions could be communicated [108]. In a later reanalysis of the arm-only study [41] it was found that some of the recognition rates were dependent upon specific gender combinations in the encoder-decoder dyads [109]. Finally, App et al. [110] found that touch was preferred over facial, or bodily expressions, for the expression of intimate emotions such as sympathy and love, and that these emotions, expressed through touch, were better recognized than through other modalities.

From the previous it can be gathered that effects of social touch are widespread and profound. Social touch affects life in all stages, from the earliest moments of child development, to building a healthy parent-infant relationship, not to mention later romantic attachments. However, the exact effects that a social touch may have regarding each of the four discussed topics, may depend on the type of touch, the interaction partners' relation, age, and gender, and may be mediated by the release of oxytocine. All of these aspects provide significant challenges to translating effects of social touch to STT. The next section will cover how STT research to date has dealt with these challenges.

4 Mediated social touch

Research into actual social touch, as well as advances in haptic technology, have inspired researchers to investigate how haptic technology can be used for social communication at a distance (see [111] for some of the earliest work). This line of research is referred to as mediated social touch [8]. Haans and Ijsselsteijn 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" [8, p. 153]. Mediated social touch is somewhat of an oxymoron, because social touch by its very nature requires physical proximity (see also [112] for a discussion of multisensory integration and physical proximity). Thus, there are differences between actual social touch and mediated social touch that need to be taken into consideration. First, unlike actual social touch, mediated social touch is not necessarily reciprocal, and the touch sensation perceived by the sender can be very different from that perceived by the receiver (e.g. pressing a force sensor that controls vibrotactile actuators [113]). Second, unlike actual social touch, mediated social touch can occur asynchronously. It is technically possible for a touch to be stored and received at a time later than when it was applied and sent. Third, mediated social touch is less sensory rich than actual social touch, not just in terms of cutaneous and kinesthetic feedback, but also in terms of feedback from other modalities which may not necessarily be present in mediated social touch.

Mediated social touch requires detection of a touch on the end of the sender, and rendering of the touch at the end of the receiver. The sender needs to be aware of the fact that his/her input causes a physical sensation at the receiver's end, while the receiver needs to believe that the felt sensation is caused by the sender. This process of attribution (see also [114]) is aided by feedback from other modalities, such as visual feedback from the input device [115], the way the source of the haptic feedback is framed (e.g. purposefully applied by the sender or not [116]), as well as the sensory fidelity of the received feedback (i.e. to what extent it feels like an actual human touch)[117].

In the next sections we discuss how these elements are represented in the design of prototypes, and to what extent these elements contribute to effects of mediated social touch. We will start in the next section by providing a brief overview of sensors and actuators for use in mediated social touch.

4.1 Sensing and reproducing touches

There are various types of touch sensors that have the capability to detect certain features of a human touch. Sensors that can detect touches on a skin-like surface emulate the human cutaneous sense [118][119][120]. Such sensors can typically detect the location, duration and intensity of a touch, and, using machine learning techniques, can be used for automatic classification of social touch gestures [119][120]. Other types of sensors can determine the position of an individual's limbs in time and space, akin to how the human kinesthetic sense works. One technique involves measuring the position of a person's limbs by attaching sensors directly to the body [121]. Another technique is to use sensors in the joints of force-feedback joysticks to derive the position of a person's limbs when interacting with the joystick [122][123].

While not yet capable of delivering the exact sensory qualities of a human touch, specific actuators can stimulate receptors for both discriminative and affective touch. For example, vibrotactile [124], air pressure [125], or purposefully designed mechanical stimuli [117], can stimulate different mechanoreceptors. Actuators capable of producing a slow stroking motion over the skin [117], could be used to stimulate CT afferents in order to address the affective touch system. Still, there is research that suggests that stroking stimuli can also be generated with a vibrotactile array, and that pleasantness responses to such stroking may be perceived similar to actual stroking [126]. Specifically designed haptic stimuli using actuation methods such as rotational friction, air puffs, and vibration can also be used to elicit affective responses in the recipients of the feedback, and for affective communication [127][128][129][130]. Similar affective responses have been found for Peltier elements [130][131], which can stimulate thermal receptors found in the human skin.

By using current sensor technology it is possible to detect features of a touch at one end, and reproduce part of this touch at a second remote location using actuators. This idea has been applied in the design of numerous prototypes that allow individuals to engage in mediated social touch.

TABLE 1
Selection of prototypes for mediated social touch.

Prototype	Meaning	Type of touch	Body location	Actuation[a]	Modalities[b]
Vibrobod [132]	Affection	Abstract, contact	Hand, abdomen, upper leg	Vib.	T, A
The Bed [133]	Affection	Contact	Hand, arm, chest, abdomen	Temp., vib.	T, V, A
The Hug [134]	Affection	Hug	Hand, arm, chest, abdomen, upper leg	Temp., vib.	T, V, A
Hug over a distance [135]	Affection	Hug	Torso	Force	T
Huggy pajama [136]	Affection	Hug	Chest, abdomen, back	Force	T
HaptiHug [137]	Affection	Hug	Torso	Force	T, V, A
Thermal hug [138]	Affection	Hug	Lower back, side	Temp.	T
Squeeze device [116]	Affection	Squeeze	Upper arm	Force	T, A
Stroking device [139]	Affection	Stroke	Hand	Force	T
Kissenger [140]	Affection	Kiss	Lips	Force	T, V, A
Affective tele-touch [141]	Affection	Contact, press, tickle	Lower arm	Force, vib., temp.	T
Tele-handshake system [142]	Greeting	Handshake	Hand	Force	T
Tele-handshake [143]	Greeting	Handshake	Hand	Force	T, V
Remote Handshake [144]	Greeting	Handshake	Hand	Force, temp.	T, V, A
YourGloves [145]	Inclusion	Holding hands	Hand	Force	T
HotHands, HotMits [145]	Inclusion	Holding hands	Hand	Temp.	T
Shaker [146]	Playful affection	Abstract	Hand	Force	T
inTouch [147]	Playful affection	Abstract	Hand	Force	T
HandJive [148]	Playful affection	Abstract	Hand	Force	T
Tug of War [149]	Playful affection	Abstract	Hand	Force	T, V, A
KUSUGURI [150]	Playful affection	Tickle	Hand	Vib.	T, V
The Tickler [151]	Playful affection	Tickle	Hand	Force.	T, V
HaptiTickler [152]	Playful affection	Tickle	Side	Vib.	T, V, A
Telephonic arm wrestling [111]	Playful aggression	Arm wrestling	Hand	Force	T
ComTouch [113]	Symbolic	Abstract	Hand	Vib.	T, A
CheekTouch [153]	Symbolic	Abstract	Hand, cheek	Vib.	T, A
ForcePhone [154]	Symbolic	Abstract	Hand, cheek	Vib.	T, A
POKE [155]	Symbolic	Poke	Hand, cheek	Force, vib.	T, A
RingU [156]	Symbolic	Abstract	Finger	Vib.	T, V
Gestural haptic interface [157]	Symbolic	Abstract	Hand	Vib.	T
TaSST [158]	Symbolic	Abstract	Lower arm	Vib.	T

a. Vib. = Vibrotactile, Temp. = Temperature
b. T = Touch, V = Vision, A = Audition

4.2 Prototypes for mediated social touch

Prototypes for mediated social touch have been designed from a wide range of design philosophies, and aim at different application areas. What all prototypes for mediated social touch have in common is that they focus on social affective communication through touch that is not purely task oriented. Similar to actual social touch, how a mediated social touch is interpreted is strongly dependent on the context in which it takes place. Different from actual social touch, mediated social touch is comparatively poor in it's sensory capabilities, and typically less flexible. Researchers have had to choose a limited set of actuation methods and body locations for the design of mediated social touch devices, in turn limiting the types of touches that can be communicated through such devices.

Table 1 shows a selection of prototypes for mediated social touch. For each prototype a number of elements is listed that are important in actual social touch interactions [11][41][159], as well as elements especially relevant to mediated social touch, such as actuation types, and the use of additional modalities. Categories relating to the use of touch in naturalistic settings [11] were used to describe the meaning of the touches emulated by the prototypes. To this categorization we added a category "symbolic" to denote devices for which the meaning of a touch arises from a shared symbolism that is not necessarily found in actual social touch interactions. Prototypes were selected on the basis of three criteria. First, prototypes should have a real functioning haptic component in them. Second, the prototypes should be aimed at social interactions. Third, the prototypes should feature a form of input and output that represents social touch in some way (see also [115] on the importance of perceived input modality).

A number of general observations[1] can be made from the

1. For a detailed description of individual prototypes see [8].

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selection of prototypes in Table 1. First, the majority of prototypes aims to communicate general positive affect, often labeled 'intimacy', towards the communication partner. This is achieved through devices that emulate intimate touches, for example hugging vests [135][136]. Another category that represents a large number of prototypes describes playful affectionate touches that serve to lighten the interaction. These interactions occur through devices that offer abstract forms of touch [146][148], playful touches such as tickling [150][151][152], or through the manipulation of a shared object [147][149]. There are a number of prototypes that feature non-task oriented symbolic tactile communication. These prototypes are for example used to add emphasis during phone conversations [113][155], or to communicate abstract representations of different types of touch [158].

Second, prototypes stimulate different body areas. Large areas of the body are stimulated by devices that emulate a hugging sensation through vests worn on the torso [135][136], devices that the user places on his/her lap [132][134], or devices that the user holds to his/her chest [133]. The most often stimulated area for all prototypes is the hand. Looking at the types of touches that are emulated by different prototypes, it stands out that many touches are static, applied to a single body location without movement over the skin. What is more, vibrotactile actuation, which does not stimulate CT afferents [160][161][162], is often used (though see [126]). It therefore seems that stimulation of CT afferents has not been a major concern in the design of many prototypes.

Finally, prototypes for mediated social touch often use other modalities in conjunction with touch. In interactions with these prototypes, visual or auditory cues can create a setting in which touches can be used, for example, for emotional expression [116][132], or adding emphasis to vocal utterances [113][155]. Conversely, visual stimuli can be used to enhance touch, by showing visual representations of, for example, a hand that applies the mediated touch [144][150]. Studies have shown that visual representations of a touch can result in responses similar to receiving an actual touch [43][45][163], therefore a multi-modal approach, combining congruent visual and tactile feedback, may be particularly promising for mediated social touch.

To conclude, many different prototypes have been designed that offer interesting interaction possibilities, and that demonstrate the technical feasibility of mediated social touch. Though the elements listed in Table 1 are important elements in the design of prototypes for mediated social touch, it should be noted that other factors, such as the communication partner, the broader context of the touch, and the timing of the touches, can have a strong impact on any potential effects of mediated social touch. These factors should be considered in the design of empirical studies into the effects of mediated social touch, which will be discussed in the following section.

4.3 Empirical studies into mediated social touch

There are two general approaches in the empirical investigation of mediated social touch (see also [164]). The first approach is characterized by efforts that focus on finding similarities between the way social touch and mediated social touch are experienced. In this line of research the aim is to reproduce certain effects of actual human-human social touch (see Section 3) in conditions where the social touch is produced by haptic technology (see also [8] for a discussion of this point). The second approach assumes a less direct connection between social touch and mediated social touch. Here, the focus is on how novel forms of haptic feedback, or novel applications of haptic feedback, may affect mediated interpersonal communication. In this section we will discuss both approaches starting with the virtual Midas touch effect, communicating affect through mediated social touch, and affective responses to mediated social touch; all topics that have also received attention in unmediated social touch research. Finally, the use of mediated social touch to enhance presence [165], a concept unique to mediated interactions, is discussed.

4.3.1 The virtual Midas touch

The Midas touch effect describes how a simple touch can result in the recipient of the touch showing more pro-social behavior towards the person applying the touch [13], such as helping to pick up dropped items [92]. Similar investigations have been undertaken in laboratory settings where the touches were applied through a mediated social touch device. Haans et al. [166] used a 'dropped items' paradigm, and found that participants who received vibrotactile feedback from a blind confederate (i.e. mediated social touch) during a computer chat session, were more likely to help pick up coins that the confederate dropped after the chat session, though this difference was not statistically significant. In an extension of their previous study, Haans et al. [103] found a significant difference for participants who received a mediated touch compared to those that did not, in a dropped-items paradigm with a non-blind confederate applying the touches. When, in a second study, the confederate was blind to the experimental condition (as in [166]) this significant difference disappeared. These findings suggest that at least part of the virtual Midas touch effect is a result of a confederate bias, where the confederate (unwillingly) adjusts certain behaviors depending on the condition, which may influence a participant's helping behavior. Interestingly, a meta-analysis of all three virtual Midas touch studies revealed an effect size similar to that for the unmediated Midas touch effect [103]. It is likely that the Midas touch effect is subject to a confederate bias as well. Haans et al. [103] suggest that using mediated social touch, with the unique ability of allowing for a blind confederate, could aid in shedding light on the extent of the confederate bias in the Midas touch effect.

Another possibility is that certain types of pro-social behavior are more strongly affected by a (virtual) Midas touch. Using an ultimatum game paradigm in which participants were made to believe they were negotiating with another player, while actual decisions were made by a computer program, Spapé et al. [167] found that direct compliance (i.e. accepting an offer) was affected by any message (i.e. audio or tactile), but that later generosity (i.e. increasing an offer) was affected uniquely by vibrotactile mediated social touch. Based on electroencephalogram (EEG) measures the authors suggest that touch can trigger memory-related processes which do not affect direct compliance, but do affect later generosity.

An approach to further reduce confederate bias in the virtual Midas touch, is to use immersive virtual reality (VR) environments. This would have the advantage of allowing the researcher to control the confederate's appearance, certain behaviors (e.g. facial expressions), and the environment in which the touch takes place. Bourdin et al. [168] had participants interact with a remotely located confederate in a VR environment. The avatar (i.e. a human-like virtual representation) of the confederate would touch the avatar of the participant and request the participant to sing along to a song that was played in the background. In one condition the participant would both see and feel the touch (as a vibrotactile stimulus to the upper arm), and in the other would only see the touch. The authors found that all participants were willing to sing at the request of the confederate, irrespective of the touch feedback they received, and suggest that the request was too easy for the physical touch sensation to have any effect. It could also be argued that the visual representation of the touch influenced compliance behavior to some extent (see also [45] on response similarities between observed and experienced touch).

4.3.2 Communicating affect through mediated social touch

In actual human-human social touch, affect and discrete emotions can be communicated through different types of touch [41]. Inspired by this, researchers have investigated the extent to which mediated social touch can be used for the communication of affect and emotions. Bailenson et al. [169] found that participants were able to use a force feedback joystick to differentially express a number of discrete emotions, using the joystick as if they were shaking someone's hand. When these expressions were played back to another group of participants using the same force feedback joystick, recognition rates of all emotions were found to be above chance level.

Successfully communicating affect through mediated social touch, may depend on the relationship between the communication partners. In a study where participants used a haptic turning knob to express four emotions (i.e. relaxed, delighted, angry, and unhappy) in either a Pong-like game, or more intimate hand stroking scenario, it was found that all emotions were recognized above chance level [170]. However, recognition rates were highest in the hand stroking scenario when the dyad of participants consisted of a couple in a romantic relationship.

The extent to which emotions can be communicated may also depend on the type of haptic feedback used, and the input used to deliver it. In a study that employed a device that could translate finger touch gestures, and squeeze gestures to vibrotactile feedback, it was found that vibrotacitle feedback could be used to communicate affective valence and arousal [171]. Squeeze gestures were found to be more suitable for the communication of low valence, high arousal states, while the finger touch gesture was found to be preferable for the communication of high valence, low arousal states. When this was taken into account recognition of valence and arousal was well above chance level. In another study, participants expressed a number of discrete emotions using a touch-sensitive sleeve worn on the forearm [172]. Participants could play back the encoded emotion to themselves, and adjust their expression. No clear differences in the way participants expressed the emotions was found from sensor data, possibly due to technical limitations of the sleeve. However, participants did described their tactile expressions of emotions in a way similar to emotional expressions through actual social touch [41].

Finally, the body location to which a mediated social touch is applied could influence the affective experience of such a touch. Haans et al. [173] conducted a study in which participants used a chat program and were made to believe they received vibrotactile mediated social touch from a male or female, to their abdomen, lower back, upper back, upper arm, and wrist [173]. Gender was found to have no effect on the pleasantness of the touches. However, touches to the stomach, arm and wrist were found to be less pleasant than those on the back, while touches to the stomach were found to be even less pleasant than those on the arm.

4.3.3 Affective responses to mediated social touch

Social touch can alter the way affective stimuli are processed, and can alter a person's affective state (e.g. [61]). Research has been conducted to investigate whether mediated social touch can have similar effects.

Schirmer et al. [174] found that both actual human-human touch from a friend, mediated social touch (force applied by a pneumatic squeeze arm band) attributed to a friend, or the same haptic stimulus attributed to a computer program, enhanced discrimination between neutral and negative images. The authors suggest that touch, regardless of its source, sensitizes ongoing cognitive and emotional processes. Contrary results were obtained by Ellingsen et al. [162] who found that, after participants were administered oxytocin, only actual human stroking touch on the forearm, and not vibrotactile stimulation on the hand, enhanced processing of images of emotional facial expressions. It is possible that differences in the types of haptic stimuli used, and the body location to which they were applied, account for these different findings [162][174].

Sumioka et al. [175] found evidence that simple physical contact can alter a person's affective state. It was found that having a conversation using a huggable communication device [176] lowered cortisol levels (an indicator of stress) in elderly participants. A possible explanation for this finding is that participants attribute the hugging of the pillow to the person on the phone [175], thus in essence receiving a passive form of mediated social touch.

Cabibihan et al. [141] directly compared actual social touch and mediated social touch in a study where participants viewed a sad video, during which they received mediated social touch from a stranger, actual social touch from their partner, or no touch at all. It was found that, indicative of the experience of sadness, participants' heart rate was lowered while they watched the sad movie, but only in the no-touch condition. Mediated social touch from a stranger, in the form of warmth and vibrations, attenuated the sadness response from watching the video to a similar extent as when participants were touched by their partner. Conversely, Erk et al. [177] found that mediated social touch in the form of mechanical hand-squeezing, did not affect recovery from watching a sad movie, as measured through several physiological measurements.

4.3.4 Mediated social touch to enhance presence

The fact that mediated social touch can occur at a distance might enhance feelings of presence, such as the feeling of being in the same room as another distant person [165]. In this sense, mediated social touch is used as a novel means of interaction that is not possible, or applicable, in actual social touch situations, which always take place in co-located space. Several studies have investigated how mediated social touch, compared to visual and auditory feedback only, can enhance feelings of presence in number of different scenarios not necessarily directly related to actual human-human social touch interactions.

One finding that is supported by a number of studies is that haptic force feedback in a collaborative shared virtual environment (SVE) can positively affect feelings of presence. It has been found that haptic feedback while collaborating in a SVE, whether this haptic feedback is task-related or not [178], can enhance feelings of social presence [179], task performance and sense of togetherness [180], with the latter effect being stronger for female participants [180]. The attribution of the haptic feedback to another person (i.e. the mediated social touch aspect), in stead of general feedback from the SVE, is likely an important aspect in enhancing feelings of social presence [149].

Importantly, like for actual social touch, the framing of the haptic feedback from another person can affect how this type of mediated social touch is perceived. Brave et al.[181] found that in a maze-navigation task in which participants were made to believe they were either helped or deceived by a remote partner, force feedback from the parter in the deceiving condition led to participants feeling a stronger sense of control, and feeling more positive about the interaction and their interaction partner, than in the helping condition.

Moreover, presence in SVE's, but also in other forms of mediated communication, can be influenced by congruent visuo-haptic feedback in mediated social touch settings [144]. Haans and Ijsselsteijn [115] investigated how participants responded to receiving vibrotactile mediated social touch on different parts of their body, while receiving visual feedback of the touches on a screen that depicted the touches applied by another person to either a touch screen or to a mannequin body. For the mannequin condition, participants reported stronger feelings of telepresence, and electrodermal activity indicated a higher level of physiologically arousal when participants saw the mannequin being touched [115].

The previously discussed work involved systems that combined visual, or audio-visual, and haptic feedback to enhance feelings of presence. Wang et al. [116] conducted a study where participants listened to a story, and, through a squeeze band, received haptic feedback from the storyteller at emotional moments in the story. Participants who attributed the haptic feedback to the storyteller, felt closer to the storyteller, than participants who attributed the haptic feedback to the storyteller's autonomic arousal. However, another study that used the same story, touch moments, and haptic feedback, with the addition of a random touch condition, found no effects of the storyteller's touches on social presence [182].

5 Simulated social touch

The previous section outlined work on social touch mediated through haptic feedback technology. In most cases communication took place between dyads of participants, or occurred with participants being led to believe that they were communicating with another person. The Media Equation theory states that humans interact with a perceived intelligent system as if the system is a human social actor [183]. Research into embodied conversational agents and social robots extends this idea by giving artificial social agents a virtual or physical embodiment that can be used during interaction with a user, for example to express emotions [184][185]. Following this line of reasoning, touches applied by a virtually or physically embodied artificial agent, could be perceived by the user as social touches. Effects of actual human-human social touch might also occur in settings where the social touches are generated by a system.

For a social robot, the relation between social touches and its embodiment is direct, as it can use its physical body to apply and receive touches. For a virtually embodied artificial agent the relation between an applied or received touch and the agent's embodiment is less direct. We argue here that for a social touch applied by, or to, an artificial social agent to be considered as such, a relation between the haptic sensation felt by the user, while either applying or receiving a social touch, and the agent's embodiment is necessary. Here, multi-modal feedback is crucial. A user will need to be able to identify the virtual agent as the source of the felt touch sensation. Congruent visuo-haptic feedback [115][186], where the sensation felt by the user is synchronized to the visual feedback from the agent's embodiment, would be essential to create the illusion that social touch occurs between a virtually embodied agent and a user [24].

The focus in this section is on intentional touch simulated by human-like artificial social agents. Though tactile interactions with animal-like robots are also found in the literature, the type of haptic feedback these robots produce is mainly aimed at simulating animal behavior [187][188], and thus differs considerably in its intentionality from purposefully applied social touches. Moreover, there are clear differences in expectations and accepted social norms between zoomorphic and humanoid robots [189], that may become especially relevant when simulated social touch is concerned [190].

In this section we will discuss literature on simulated social touch according to a number of common topics that appear in the literature. Virtual agents and social robots will be discussed separately, based on differences in their embodiment and the use of touch in interactions with them [190].

5.1 Touching virtual agents

Two distinct advantages of adding touch capabilities to a virtual agent can be defined. First, by allowing the agent to touch a user the agent gains an additional channel for

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expression. This would be a step towards virtual agents that can communicate using all subtleties of expressions that are available to human beings. Second, the virtual nature of the agent as well as the (virtual) environment in which the agent resides, offer unique opportunities for the controlled study of social touch. Being able to control both the behaviors of the agent as well as the situation in which the interaction between the agent and a user takes place, allows for interesting experimental paradigms for social touch. The use of augmented reality (AR) or VR technology could be especially fruitful here.

An important challenge in adding touch capabilities to virtual agents is that their virtual embodiment does not directly afford touch interaction. Therefore designers and researchers have had to find ways for allowing virtual agents to 'reach out of the screen' and touch the user. This could involve having users wear actuators, such as vibrotactile actuators, on their body that can be activated in synchrony with a predetermined agent behavior [24]. In situations where the user applies a touch to the agent, the challenge is to let users 'reach into the screen' in order to apply a touch. One approach involves the use of a force feedback joystick that controls a pointer in the virtual space [191]. Virtual objects encountered by this pointer, such as touching an agent's torso, can be rendered haptically using the joystick, thus providing the user with a sense of touch. Bidirectional touch between virtual agents and users could be achieved by combining both approaches or by using passive haptic feedback to allow users to touch the agent, for example through the use of a mannequin [192]. We will provide an overview of designs and studies that use these techniques to introduce simulated social touch in interactions between virtual agents and humans.

5.1.1 Touch to enhance emotional expressivity of virtual agents

A major direction in virtual agent research is the expression of emotions through facial expressions [184]. Potentially, the addition of touch capabilities could enhance the emotional expressivity of virtual agents. Bonnet et al. [193] found that the recognition of certain emotional facial expressions made by a virtual agent was enhanced by adding congruent haptic expressions of emotions, using a force feedback joystick. Conversely, for some emotional expressions, haptic feedback deteriorated recognition, possibly due to confusions in the haptic expression of certain emotions (e.g. sadness, surprise). Gaffary et al. [194] set out to investigate how haptic emotional expressions, expressed through a force feedback joystick, can enhance the recognition of visually more ambiguous emotions expressed by a virtual agent. While pure visual expressions were better recognized than pure haptic expressions, visuo-haptic expressions were better recognized than either visual or haptic expressions alone. The authors conclude that high valence emotions are better expressed visually, while high arousal emotions are better expressed haptically.

It has to be noted here that in the studies of Bonnet et al. [193] and Gaffary et al. [194] there was no clear relation between the embodiment of the agent and the haptically expressed emotions. An interesting avenue for future research would be to conduct similar studies with congruent visuo-haptic feedback, where the agent uses its embodiment to express each emotion through touch. A first step in this direction was taken by Bickmore et al. [195] who designed a virtual agent that was partially physically embodied. The virtual agent's face was displayed on a computer monitor situated on top of a mannequin body. One of the hands of the mannequin was equipped with an air bladder that could be inflated, producing a squeezing sensation in the hand of a user holding the agent's hand. It was found that, using only touch, squeeze intensity and frequency could be used to communicate emotional valence and arousal. However in combination with visual and auditory modalities, touch had little effect [195]. Finally it was found that positive effects of the agent's touch were mainly found for participants who were more comfortable with social touch in general [195].

5.1.2 Touching virtual agents for training

Social touch can be used instrumentally, in a task-related fashion [11], especially in medical, or therapeutic settings [15]. Because training staff to become proficient in such uses of touch can be difficult and time-consuming, this is where virtual agents can be useful. Kotranza and Lok [192][196] designed a virtual agent that is visible in VR through a head mounted display, and that has a mannequin-like physical embodiment which the user can touch. The authors propose that this type of "mixed reality human" can be used in training scenarios for breast examinations. The physical embodiment of the agent provides passive haptic feedback, whereas areas of the body relevant to the scenario (i.e. clothing and the breast) contain sensors to detect touches. The virtual representation of the agent can respond to touches detected through the sensors, by using speech, gestures and facial expressions. It was found that medical students experienced a greater feeling of presence, and employed touches similar to those used in a real breast examination [192]. In a comparison with a training using an actor, it was found that medical students rated both experiences similar on believability and perceived educational benefits, and spent an equal amount of time palpating the breast [196]. Kotranza et al. [197] enhanced the mixed reality patient with the ability to visually or visuo-haptically, using servo-motors to move the mannequin's arm, touch the user, as well as respond to user's touches. Studies showed that medical students used touches to communicate empathy, concern, comfort, and to gain the virtual patient's compliance. Furthermore, it was found that viso-haptic touch from the virtual patient successfully communicated the virtual patient's fear, and made it seem more human-like [197].

5.1.3 Touching virtual agents as social actors

Adding social touch capabilities to a virtual agent expands the communicative repertoire of the agent, and could make it a more complete social actor. Following this line of reasoning Huisman et al. [24] present the design of a virtual agent that can touch the user's forearm. Users, wearing a vibrotactile display, view their own forearm through a tablet running an AR application. When the virtual agent, visible on a computer monitor, applies a touch, the agent leans forward and the agent's arm and hand become visible on the tablet. At the moment the agent's hand visually touches the user's arm, vibrotactile feedback is generated

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in the same location, simulating a touch by the agent. In a pilot study, the authors failed to find an effect of the agent's touch on increasing compliance to a request made by the agent, potentially due to large individual differences in participant's trait compliance [24].

Huisman et al. [198][199] conducted a study in which two virtual agents, visible through a hand-held tablet in AR, interacted with a user in a collaborative or competitive game scenario. Participants wore a vibrotactile display on both their upper arms and on their abdomen (for general feedback during the game). Once prior to playing the game, and twice after playing the game, one of the agents would apply a touch to the right or left upper arm of the participant. Touches were visible through the tablet's screen and could be felt by the participant through the appropriate vibrotactile display. In both the collaborative and competitive condition the touching virtual agent was rated higher on interpersonal warmth, than the non-touching agent. This effect was more pronounced for participants who were more comfortable with social touch in general [199].

Bailenson and Yee [191] conducted a study in which participants, wearing a VR headset and using a force feedback joystick, were tasked with brushing virtual dirt off of male and female virtual agents, and virtual geometric shapes. Participants touched virtual humans with less force than virtual objects, touched the face of virtual agents with less force than the torso, and touched male virtual agents with more force than female virtual agents. As the authors suggest, haptic differentiation between touching virtual agents and virtual objects, and between body location and gender, points to an enhanced sense of co-presence, where participants treat the virtual agents more like social actors [191]. Moreover, the visual appearance of the virtual agent may influence touching behavior. Tremblay et al. [200] found that participants, using two haptic devices, hugged virtual agents differently depending on their gender and body size. Male participants hugged normal weight female virtual agents longer than overweight female agents, while female participants hugged normal weight male virtual agents longer than overweight male agents.

5.2 Touching social robots: Tactile HRI

Physically embodied artificial social agents offer the most direct means for social touch interactions between humans and artificial social agents. The field of tactile human robot interaction (Tactile HRI) is concerned with two themes in the research field of robotics, namely: tactile detection, and HRI [201]. Detection often occurs through, soft- or hard shell skin-type sensors, or through sensors in the robot's joints [201]. For example, Yoshikai et al. [202] present a small humanoid robot with a soft urethane shell that contains touch sensors. The sensors can detect 3D force distributions, allowing the robot to respond to physical interactions such as being picked up, and hugged. Similarly, CB2 [203] is a child-sized robot that features a soft silicon skin with embedded touch sensors, which allow the robot to respond to physical contact from a human. HRI that involves physical interactions between the robot and a human, can be studied from the perspective of safety (e.g. accidental contact) or from the perspective of behavior- development and execution by the robot [201]. Here we are interested in the latter and will focus on what potential effects touching or being touched by a social robot might have on the human interaction partner.

5.2.1 Tactile HRI and care

Social robots have a wide range of potential applications in health care settings [204], For example, children with autism spectrum disorder (ASD) could benefit from interactions with social robots [205]. In such care-related HRI applications, simulated social touch could play an important role.

Robins et al. [206] propose that tactile interaction with social robots can help children with ASD, who often suffer from hypertactility [207], to get accustomed to social touch, potentially making them more comfortable being touched by a real person. To this purpose Robins et al. [206][208] had children with ASD physically interact with a social robot in a free play session, and found that the children used different touch behaviors to engage with the robot [206][208]. In a follow-up study, Robins et al. [209] studied the interaction between children with ASD and a social robot that could respond to touch in a playful cause-and-effect game. The robot responded positively to light touch and negatively to harsh touch, by vocal utterances, facial expressions, and body movement. After repeated interactions with guidance from the experimenter, children were able to develop a non-aggressive touch interaction style with the robot. Additionally, an approach where the robot gives appropriate multi-modal feedback to being touched, can have positive effects on the body awareness of children with ASD [210].

In a scenario where an abstract humanoid-robot acted as a nurse, and participants acted as patients, Chen et al. [211][212] had the robot apply a stroking touch to the participant's lower arm. The meaning of the touch was framed as either instrumental (i.e. cleaning) or affective (i.e. comforting), and was either preceded by a verbal warning from the robot, or not. Participants rated the instrumental touch as more necessary than the affective touch, and experienced lower emotional arousal and higher emotional valence for the instrumental touch compared to the affective touch. It is possible that the use of a social robot with a more friendly appearance could have altered the results [212]. Nevertheless, these findings show that the perceived intent of the received tactile sensation influences participants' perception of simulated social touch.

5.2.2 Tactile HRI for attitude and behavior change

Social touch simulated by a social robot could be used to positively influence the user's attitude towards the robot, potentially leading to the user adopting more favorable behavior towards the robot as well. Hieida et al. [213] investigated how physical contact in the form of hand holding in the early stages of child-robot interaction can positively influence a child's attitude towards the robot. After holding the robot's hand early on in the interaction, children thought the robot was more human-like, were less fearful of the robot, and played more actively afterwards. The authors suggest touch can pave the way for building a relationship between the child and the robot.

Cramer et al. [214] conducted a video-based study, and found that tactile behavior and pro-activeness of a robot

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assisting a user with a computer problem, influenced perceptions of that robot. A robot that was observed to be proactive and applying a touch was perceived by participants as less machine-like. A reactive robot that did not use touch was perceived as more machine-like and less dependable. Furthermore, the absence of social touch by the robot resulted in participants with a positive attitude towards robots, to rate it as more machine-like.

Nie et al. [215] found that actual physical contact with a social robot in the form of holding the robot's warm hand, resulted in participants perceiving the robot as significantly more friendly, trustworthy and human-like, while watching a horror movie. However, warm touch could not attenuate the scare effects of the horror movie.

Some studies have found indications that simulated social touch by social robots can elicit the Midas touch effect [13]. Fukuda et al. [216] investigated the Midas touch effect in an ultimatum game played between a social robot and a participant. The robot applied a stroking touch to the participant's arm when proposing unfair offers. EEG measurements indicated that activity in brain areas related to feelings of unfairness was suppressed by the touch, despite the fact participants still rejected all unfair offers. Behavioral evidence for the robotic Midas touch effect was found by Nakagawa et al. [217]. After a stroking touch to the hand by a small humanoid robot, participants spent significantly more time on a repetitive task, completed more actions during the task, and rated the robot higher on friendliness, compared to no touch, or passive touch (handholding). Note that, using a similar experimental setup, Huisman et al. [24] did not find any such effects on compliance for touch by a virtual agent.

6 Conclusions

In this survey an overview of research from diverse fields, including neuroscience and social psychology, that deal with the human sense of touch in social interactions, was presented. Work on actual social touch has inspired researchers to investigate the use of haptic technology for social touch. In the current survey these efforts were brought together under the title social touch technology (STT). Research into STT is beginning to move beyond explorations (see [8][112]). It is using more formal methods such as validated questionnaires (e.g. [218]) and psychophysiological measures, and is starting to shed light on factors underlying STT. The continuing effort to improve on the methods used is especially important for STT when comparisons are made with actual social touch.

Similar to results obtained for actual social touch, STT research has found a Midas touch effect in mediated [103][167] and simulated [216][217] social touch. Indications that the Midas touch effect in general is partially explained by a confederate bias have also been found [103]. Future research should capitalize on the use of AR/VR technology and social robots to investigate the Midas touch effect and the potential confederate bias in more detail.

As for actual social touch, mediated social touch has been found to be suitable for the communication of emotions, but successful communication of emotions depends on the methods of touch input and output used [169][172][195]. Current research indicates that force feedback devices are more successful in this regard [169]. It should also be noted that studies were conducted in lab settings and that the expression of emotions through touch may depend on contextual factors [170][173], thus future research in this direction should ideally include clear contextualizations to further investigate the expression of emotions through STT.

While for actual social touch there is evidence of stress reducing effects, the findings for STT on physiological responses is largely inconclusive, likely due to differences in the way touches were applied and measurements were taken [141][177]. It would be worthwhile to further investigate how specific types of haptic feedback could produce certain physiological responses, for example with the aim of reducing stress.

The most robust finding regarding STT is that it enhances social presence in shared virtual environments [115][149][179], and makes artificial social actors seem more human-like [197][199]. It is plausible that a sufficient level of social presence is necessary for a person to experience a certain type of haptic stimulation as social touch [8]. Thus STT in relation to presence research remains a promising area of future research.

An important recommendation that can be made for future STT research in general is to investigate structurally, the interplay of top-down (i.e. attribution) and bottom-up processes (i.e.. somatosensory processing of haptic stimuli). Under which circumstances is it necessary to provide a more realistic, human touch-like form of haptic stimulation, and when does vibrotactile stimulation suffice in STT? The availability of additional multimodal cues should be considered in such a question, not just for providing information about the touch and toucher, such as their gender [44], but also for providing information about the broader context in which the touch takes place, for example a competitive/collaborative game scenario [199] or a calming or instrumental touch [212].

The observed effects of STT occur despite the fact that the haptic stimuli used in STT, such as vibrotactile or force feedback, offer only part of the physical composition of an actual human touch (see Sections 4.1 and 4.2). It would therefore seem that the effects of STT occur not because the haptic feedback feels particularly like a human touch, but because the haptic feedback is attributed to either another person in a remote location, or to an artificial social actor such as a virtual agent. As was discussed in Section 4 it is important to ensure that the recipient of a touch is aware of the fact that the felt haptic sensation originates from another social actor. Only when a haptic sensation is attributed to another social actor can it serve as a social signal, and only when a haptic sensation is considered as a social signal does it have the potential to produce effects similar to social touch. Therefore one of the aims of STT research should be to investigate which factors contribute most strongly to a person attributing a haptic sensation to another social actor.

As we have seen in Sections 4.2 and 4.3, feedback from other modalities, such as visual [115] and auditory [116] feedback, can be important factors for appropriate attribution of a haptic sensation to take place. Careful use of multimodal feedback might be especially important for the artificial social actors discussed in Section 5, which have to contend with the fact that they may not be automatically perceived as social actors, and may even lack a physical body that affords touch (see Section 5.1).

With this another question arises, namely to what extent the physical properties of the haptic stimuli used in STT matter, given that effects can be obtained with, compared to actual touch, strongly degraded sensations. Section 4.2 shows that designers and researchers have explored diverse actuation methods, indicating at least an intuitive drive for exploring the influence of the qualities of the haptic sensation in STT. Moreover, there is evidence that at least part of the effects of STT may also occur in a bottom-up fashion [174]. Furthermore, it is plausible that certain types of haptic stimuli are more suitable for social touch interactions than others, such as in the communication of affect [171], and for stress reducing responses [141][177]. It is plausible that the use of warmth, and its relation to interpersonal warmth [219], may be an important factor in stress reduction through STT. Investigating which types of haptic stimuli are more suitable in specific settings is an interesting area of future STT research. Research could capitalize on recent discoveries in neuroscience and investigate stimulation of CT afferents and addressing the affective touch system, to investigate potential bottom-up effects (Section 2.2).

In Section 4.3 we discussed that following paradigms from social touch research is one way to demonstrate response similarities between social touch through haptic technology and actual social touch. Further evidence for such parallels is important as a foundation for STT. On the other hand, such a foundation may also be important for the continued research into actual social touch. If effects of STT show parallels to actual social touch, it may be possible to employ STT as a research tool for actual social touch. Here we want to draw attention to three ways in which STT could help social touch research. First, STT can offer control of the sensory qualities of the haptic stimulus. Haptic interfaces allow for minute control over sensory qualities of a haptic stimulus, much more so than actual human touch. Using haptic technology, the timing of touches, the type of feedback produced (e.g. vibrotactile, warmth), and the exact body location to which it is applied, can be controlled. This would allow for studies into the role of individual submodalities of touch, such as vibration and force, in social touch interactions. The study of CT optimal touch already benefits from the use of haptic interfaces to enable exact control of the stroking touches' velocity and force [36][37].

Second, STT can help social touch research by offering control over contextual factors through the use of multimodal feedback, most potently through VR/AR. Using such technology, information from other modalities (e.g. visual, auditory) that can strongly influence the interpretation of a touch, can be controlled. Having control over such factors may be especially valuable for disentangling effects of touch from those of other modalities. An example of using STT in such a way is found in work on the Midas Touch, for which, using mediated social touch, a confederate bias was found, which could not have been uncovered using actual social touch [103].

Finally, STT can offer social touch research accurate measurement techniques, and the possibility of automatic classification of touches [119] afforded by sensor technology and machine learning. The use of such techniques is a good way of obtaining behavioral data related to social touch, that in regular social touch interactions is difficult to obtain. In turn, gathering such behavioral data could also prove invaluable for the generation of social touches by artificial social agents, such as social robots.

This interaction between social touch research and STT research is important when the applications of STT are considered. For example, artificial social agents, as discussed in Section 5, have a need to detect and understand touch behavior of human communication partners for the generation of appropriate responses. The use of social touch might actually be necessary for the forming of a bond, and to match expectations of social robots [190], whose physical embodiment affords touch. It is to be expected that as social robots become more prevalent in areas such as education and healthcare, such social touch interactions become more important, especially considering the effects of actual social touch for wellbeing, the communication of affect, and the forming of social relationships as discussed in Section 3.

What is more, advances in VR and AR technology, not to mention the current popularity of these technologies, enables new ways to interact with virtual characters, and remotely located people. Haptic technology used in VR and AR is also becoming increasingly unobtrusive and provides ever more realistic sensations (a good examples is HTC Vive's 'bow and arrow demo'). With such technologies becoming more commonplace as methods for social communication, as attested to by interest from social media companies such as Facebook, it is to be expected that this technology will ultimately feature social interactions in combination with haptic technology. Thus STT may play a role in future applications for gaming and entertainment, and remote interpersonal communication.

Finally, it is not unthinkable that, provided further evidence for similarities between actual social touch and STT is found, that STT, in combinations with the discussed enabling technologies and applications, could provide social touch in situations where actual social touch is currently found to be lacking. For example in elderly care where the number of contact hours is limited [15]. Future research, and applications that flow from this research may thus enable STT to extend the reach of social touch.

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