Reach Out and Touch Me: Effects of Four Distinct Haptic Technologies on Affective Touch in Virtual Reality

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ABSTRACT
Virtual reality presents an extraordinary platform for multimodal communication. Haptic technologies have been shown to provide an important contribution to this by facilitating co-presence and allowing affective communication. However, the findings of the affective influences rely on studies that have used myriad different types of haptic technology, making it likely that some forms of tactile feedback are more efficient in communicating emotions than others. To find out whether this is true and which haptic technologies are most effective, we measured user experience during a communication scenario featuring an affective agent and interpersonal touch in virtual reality. Interpersonal touch was simulated using two types of vibrotactile actuators and two types of force feedback mechanisms. Self-reports of subjective experience of the agent's touch and emotions were obtained. The results revealed that, regardless of the agent's expression, force feedback actuators were rated as more natural and resulted in greater emotional interdependence and a stronger sense of co-presence than vibrotactile touch.

CCS Concepts
• **Human-centered computing~Haptic devices** • **Human-centered computing~Virtual reality** • **Human-centered computing~User studies**

Keywords
Virtual reality; Haptic technologies; Affective communication; Facial expressions

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1. INTRODUCTION
Being able to convey mixtures of auditory, visual, and tactile signals is an essential part of our everyday affective communication repertoire. Thus, it is not surprising that there have been several attempts to create multimodal systems for affective virtual communication [1,6,23].

The majorities of developed systems rely solely on the senses of vision and hearing and do not allow for tactile communication. However, various researchers have demonstrated the value of touch in affective virtual communication [27,28], showing for instance how receiving mediated touch reduces stress and establishes social connectedness between users [13,32]. Although the importance of touch has long been acknowledged in the field of affective computing, relatively little is still known about how users experience the mixture of visual and tactile affective feedback. Understanding of this cross-modal integration is even scarcer with regard to immersive virtual environments with embodied affective agents.

So far, the cross-sensory aspects of tactile communication have mainly been studied in the field of social psychology. The essentially multimodal nature of affective communication was recently illustrated by App and colleagues, who showed that people prefer different channels of communication depending on the emotion they are willing to convey [2]. For instance, individuals smile when signaling amusement, but they touch when communicating love and sympathy. In the dynamic flow of interaction, however, all channels are used simultaneously. We combine different modalities in order to vary the subtleties of emotional messages and thus allow modulating the messages form a particular channel (e.g. facial expressions). A recent EEG study, for example, investigated the effect of mediated touch on social decision-making and found that touch was perceived differently depending on whether the toucher's preceding offer was fair or unfair [31].

Besides the cross-modal interactions between tactile and visual senses, we are also able to communicate a variety of emotions solely via our tactile sense. Hertenstein et al. [17], for instance, showed that people can communicate at least six distinct emotions by varying the way they touch another person's skin. Similar results have also been found when using virtual touch. Bailenson and colleagues [3] used a force feedback haptic device allowing participants to touch each other. Receivers' task was to recognize which emotions the sender was trying to communicate. Results indicated that users were above chance when recognizing emotions conveyed via haptic devices, but not as accurate as when using non-mediated touch.

Thus, at least two things should be taken into consideration when creating multimodal affective communication systems involving tactile feedback. First, the visual emotional context in which touch is delivered may affect the interpretation of the touch. For instance, receiving a gentle touch from a happy virtual agent is not necessarily the same as receiving the same touch from an angry one. Second, because the emotional information conveyed by a haptic device changes as a function of its tactile features, it is likely that some technologies are more suitable for communicating certain emotions.

To find out how the experience of touch depends on the visual emotional context and the type of haptic technology, we designed a user study and systematically compared these factors. Thus, we investigated the effect of mediated interpersonal touch on tactual perception and overall affective experience while varying the haptic technology and the toucher's emotional expression. A validated set of animated facial expressions indicating five basic emotions were used to manipulate the emotional context of tactile communication. In order to investigate the suitability of different haptic devices for affective tactile communication, both tactile and affective user experiences were measured. As an index of tactile perception, users evaluated the naturalness and intensity of the touch. Affective experiences were investigated by asking users to evaluate to what extent they felt influenced by the virtual agent (emotional interdependence) and whether the agent captured their attention (co-presence). These variables were assumed to capture the key aspects of the socio-emotional experience of the users within a setting that provided for limited social interaction.

In the following section (section 2) we will describe the related empirical work, after which (section 3) we will introduce the four different haptic technologies used in the current study. Then, in section 4 we will give an overview of the experimental procedure and describe the virtual reality system. In section 5 the results of the statistical analyses will be covered, and finally, in section 6 we will discuss the findings and relevant applications.

2. RELATED WORK

Even relatively simple tactile actuators can be used to communicate a wealth of socio-emotional information and induce many psychological consequences similar to those found in natural touch [11]. Mediated touch has been demonstrated to reduce distress induced by watching a sad video [4] and to increase shared amusement while watching a comedy clip together with other users [32]. In addition to affective modulation, receiving virbrotactile signals from other users has been shown to promote co-presence and interpersonal connectedness [26] as well as elicit helping behavior and generosity in social decision-making paradigms [14,31].

To date, the study of affective touch has been marked by idiosyncrasies related to various laboratories using customized in-house equipment to implement touch, so it is possible that the affective outcome depends on the technology used. Indeed, it has been suggested that different haptic technologies convey different emotions [3], so it is a distinct possibility that some haptic technologies are better suited for affective communication than others.

In order better to understand the existing features of existing haptic technologies, we can simplify the variety of systems by clustering them into two subcategories: vibrotactile and force feedback actuators. Using a vibrotactile actuator is a relatively common and cheap method for virtual tactile communication. A typical vibrotactile feedback system utilizes a small linear resonant actuator placed on the surface of the skin. Vibrations are traditionally used as a part of touch screens or other physical interfaces [18], but they have also been used in tactile communication [14,19,31] and for orientation and pointing support [22].

An alternative to vibrotactile feedback are force feedback systems, which are generally more complex in terms of technology and design and thus less common in tactile communication systems. A good example of a force feedback device is the robotic arm developed by Nakanishi et al. [26], which was used to deliver pressure on a participant's palm in order to simulate a handshake. Taking into account the tactile features of real interpersonal touch, it can be stated that force feedback systems approximate real human touch better than vibrotactile devices, since human touch and force feedback both rely on the cutaneous sense of pressure [13]. Nevertheless, it is also possible that vibrotactile feedback is likewise suitable for communicating certain emotional messages, such as fear or anger, as the user might understand the rapid displacement of skin as representing an alarm signal.

Different haptic technologies should be thus compared in the context of varying emotional cues. Some emotional cues, such as facial expressions, have been studied more than others (e.g., Ekman et al. [7]). Psychological studies on facial expressions have, for instance, demonstrated how facial actions are used similarly across different cultures when communicating anger, fear, disgust, happiness, and sadness [8,20]. There have also been continuous efforts in 3D modeling and animation to enable realistic facial gestures in virtual agents [5,12]. That is why facial expressions can be considered the best candidate for emotional stimuli when comparing the affective outcomes of different haptic technologies. A recent work of Ahmed et al. [1] shows how facial expressions of a virtual agent, and both vibrotactile and force feedback haptic technologies can be used for eliciting affective outcomes during different game events. Haptics and expressivity of the agent contribute to expand the use of implicit and affective interaction towards symbiotic human-computer interfaces [21].

3. FOUR HAPTIC TECHNOLOGIES

The finding that the socio-emotional outcomes of touch may depend on the type of tactile stimulation [10] motivated us to look at different technologies to appropriate touch feedback. Here, we are interested in accessible and low-cost technologies that can be used to mimic interpersonal touch. Our basic setup includes a person sitting with a hand resting on the table in front of a 3D model of another person, that is, the agent. The touch sensation is created when the virtual agent touches the user's resting hand from above. In order to compare different haptic technologies in the context of multimodal affective communication, we selected four technologies: two force feedback actuators and two vibrotactile actuators.

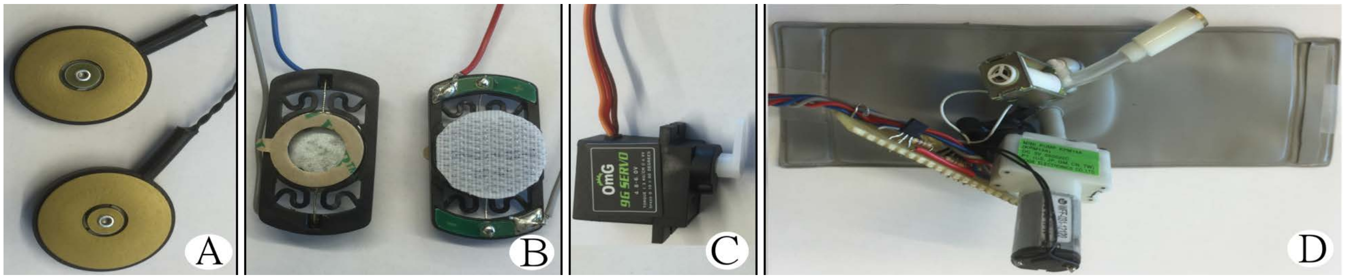

Figure 1. Four different actuators used in the investigation. (A) C2 tactor, (B) haptic exciter, (C) servo motor, and (D) pneumatic actuator.

3.1 Vibrotactile Actuators

Traditionally, research on tactile communication and tactile psychophysics (e.g. Sherrick, 1985, [29]) has relied on vibrotactile actuators that apply voltage to piezoceramic reed benders in order to produce mechanical displacements We started with classic vibrotactile actuators that were similar, namely C2 tactors. The C2 is a small wearable linear vibrotactile device that is optimized for use against the skin. C2 actuators have been used commonly to provide haptic feedback in text entry [18] as well as interpersonal tactile communication [31]. In the current study, two ATAC C2 tactors (www.atactech.com/PR_tactors.html) were placed on the dorsal side of the hand.

Given that the C2 actuator vibrates only the contact point of the skin, an alternative vibrotactile device with a broader vibrating area, a haptic exciter (Tectonic's 14mm, 8ohm TEAX14 C02-8, www.tectonicelements.com/audio-exciters), was also used in the study. The exciter generates bending waves that stimulate the surrounding tissue and bone structure, creating a diffusive vibration sensation. In this study, two exciters were placed on the metacarpal bones on the dorsal side of the right hand.

3.2 Force Feedback Actuators

The fact that real human touch doesn't just stimulate our cutaneous sense but also generates force on the contact point led us to complement the investigation with alternative technologies, specifically, force feedback actuators. Using a force feedback actuator can mimic the pressure induced in real physical touch. We therefore selected two different mechanical actuators and developed two alternative approaches to apply pressure on the dorsal side of the user's hand.

The first approach utilizes a pneumatic actuator that transduces energy into mechanical motion using compressed air. The mechanical force can be then applied on the skin. Pneumatic actuators are mainly used for measuring blood pressure, but they have recently been applied in haptic feedback devices as well [15,25,30]. For instance, Shimoga et al. [30] utilized pneumatic actuators to provide haptic feedback to the user's hands and fingers. Of the four different pneumatic designs presented by Shimoga et al. [30], we were particularly interested in the "air-ring" approach, in which a plastic tube is inflated around the user's finger in order to give haptic feedback from a system. Inspired by the air-ring approach, we also used a pneumatic actuator to inflate a tube around the user's metacarpal area. The materials used in the pneumatic actuator (tube, air pump, escape valve) were adopted from a regular blood pressure monitor.

As a second approach to force feedback actuators, we utilized a micro servo motor (9g, speed 0, 10s/60, torque 1.3kg/cm at 4.8V) that is, a rotary actuator designed to control angular or linear movement. Servo motors are commonly used to control robotic arms that shift mechanical elements. However, there are some cases in which they have been used as part of a tactile interface. Wang et al. [34], for example, designed an armband to provide touch feedback in a remote social interaction context. The mechanical part of this armband was equipped with a servo motor, which squeezes the armband and creates pressure on the user's arm. Along similar lines, we designed a glove that applies pressure by squeezing the metacarpal area of the user's hand.

4. METHOD

4.1 Participants

Seventeen university students (10 male, 7 female, 26.8 ± 2.9 years old) volunteered to take part in the study. They signed informed consent forms prior to the start of the experiment, and afterward they received a movie ticket for their time. One participant was removed from data analysis for technical reasons.

4.2 Test Setup

4.2.1 Visual Stimuli

The virtual agent used in the study was the original one provided by Faceshift (www.faceshift.com). The agent displayed five types of emotional expression (happiness, sadness, anger, fear, and a passive, "neutral" control condition). These were recorded prior to the study by capturing the live presentation from a professional actor using the Faceshift algorithms. Movement data was then projected onto the agent's face. Expressions were manually adjusted to last exactly 4 s starting and ending with the neutral expression. For each distinct emotion type, three alternative animations were created. The expressions were then validated by measuring recognition accuracy of 14 participants who watched and classified the animations presented on a normal computer screen. The five emotional expressions with highest accuracy were used in the present experiment (happy, sad, anger, fear, and neutral).

The virtual agent and the environment were presented using Oculus Rift VR with a head-mounted display (HMD, Oculus Rift Developer Kit 2, Resolution 960 x 1080 per eye, Refresh Rate 75 Hz, 100° Field of View [nominal]). The user's head movements were tracked at 1000 Hz using a three-axis accelerometer, a gyroscope, and a magnetometer as well as an external positional tracker (www.oculusvr.com). The right hand of the user was tracked using a Leap Motion Controller (www.leapmotion.com) that was placed on a table 16 cm below the hand. The distance between the hand and Leap Motion controller was held constant using a transparent glass table (see figure 2). Finally, a Unity 3D game engine (version 4.5.4) was used to implement the experimental system.

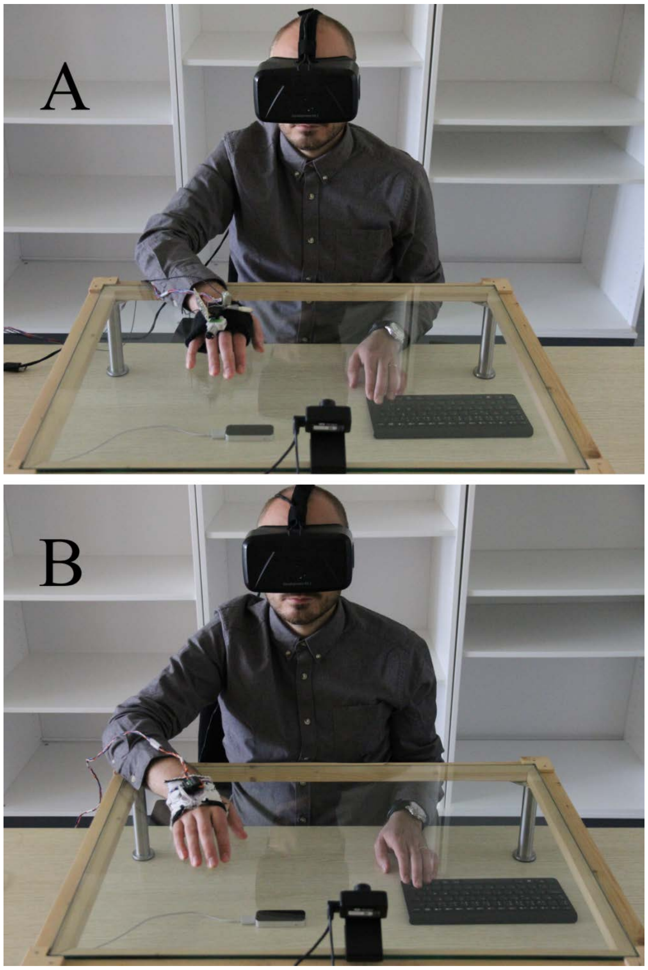

Figure 2. Test setup and user interaction. The touch was applied using four tactile technologies embedded in two gloves. (A) Pneumatic-C2 glove, and (B) servo motor-haptic exciter glove.

4.2.2 Haptic Stimuli

Four different types of haptic technologies were investigated. These are C2 tactor, haptic exciter, pneumatic actuator, and servo motor. For simplicity of use, we first designed two gloves, one with a pneumatic device and one with the servo motor. We then placed the C2 tactor in the free space available in the pneumatic glove and the exciter in the servo glove. The actuators in the gloves were controlled through an *arduino uno* microcontroller (www.arduino.cc). The gloves were designed to fit different hand sizes.

The pneumatic glove (Figure 3) was made using a rubber band with a plastic tube attached to it. An air pump with escape and intake valves was attached to the glove.

The servo glove (Figure 4) was tailored using a piece of cotton fabric. We attached the micro servo motor on top of the glove. Three pieces of elastic tape were attached to the glove, which were connected by a thread to the horn of the servo motor. The servo motor rotates in order to pull the thread, which creates tension in the elastic tape and applies pressure to the user's hand. This mimics the sensation of someone gripping the hand, much like the pneumatic prototype. This particular design was chosen because the inflation of the pneumatic version is relatively slow.

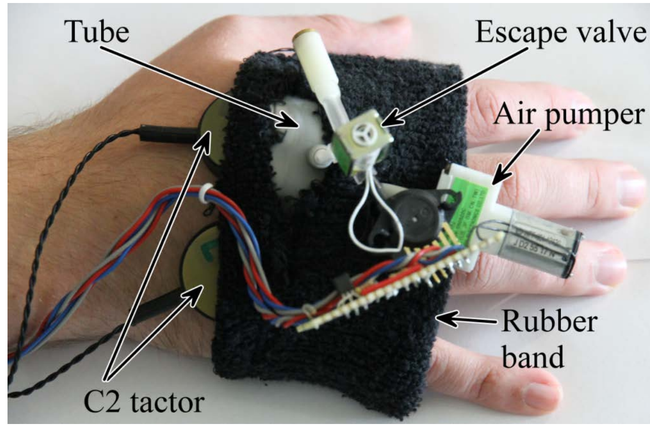

Figure 3. Pneumatic glove including the C2 tactors.

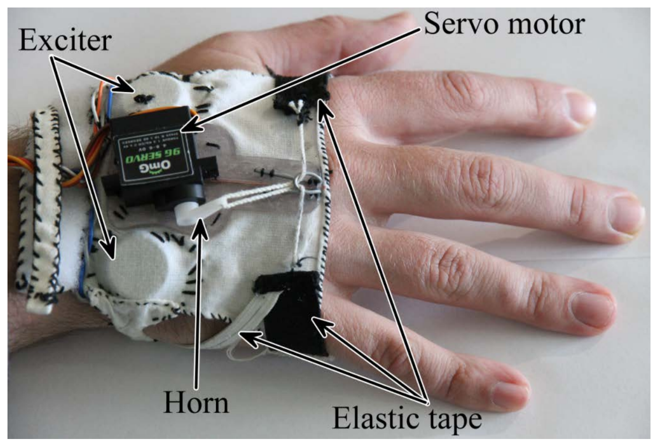

Figure 4. Servo glove including the haptic exciters.

4.2.3 Tactile Stimulus Intensity

Zmigrod et al. [35] used two different intensities for vibrotactile feedback, namely low and high frequencies, to investigate how these two intensities interact with audio and visual modalities. Hertenstein et al. [16,17] used three different human touch intensities: *light*, *moderate*, and *strong*, to investigate how emotion can be recognized via touch. Similarly, we designed two different stimulus intensities: *low* and *high*. Taking into account the fact that the skin of the human hand is sensitive to vibrations between 20 and 200 Hz and that square waves are perceived to be more intense than sine waves [33], we selected 35 Hz square waves to represent the *low* and 100 Hz square wave to represent the *high* intensity, for both C2 and Exciter actuators. For the pneumatic glove, the full inflation (110kPA or 15.95psi) of the tube was considered *high intensity* and half inflation (100kPA or 14.50psi) was considered *low* intensity, whereas in the servo motor glove we used ~180-degree rotation of the horn to index the *high* intensity and ~120-degree rotation to index the *low* intensity.

Figure 5: Trial sequence. The user moved his or her virtual hand to the green area (A) before the agent was displayed. Touching the blue cross (B) started the emotion animation (C). The tactile stimulus was initiated as the agent reached the user's hand (D).

4.3 Procedure

As illustrated in Figure 5, a visual cue was presented as a common starting point for every trial. As soon as the participant moved his or her virtual hand over to the cue, the trial started: the agent appeared wearing a neutral expression. After touching the blue crosshair, the emotional expression animation began. Following a randomized interval of 2.5 ± 0.3 s, the animation of the agent's reaching gesture was played. After 1 s, the agent's hand reached the participant's virtual hand. The haptic feedback was then initiated. Following another 1 s, the questionnaire was shown (see section 4.4), and participants were asked to fill it out using the arrow keys of a PC keyboard (with their other, non-virtual hand). Due to the noise made by the force feedback actuators, a masking sound was played throughout the experiment. This was done in order to prevent any evaluation biases arising from the auditory cues.

4.4 Measurements

The survey consisted of five items. The first two items used Likert scales to assess how natural and intense the user found the experience of the touch ("How natural was the touch?" "How intense was the touch?"). The following two items measured by the Likert scale, were taken from the co-presence module of the game experience questionnaire (GEQ, [24]). The items concerned judgements of the communicated affect with one item concerning emotional interdependence ("I felt influenced by the agent's mood") and another concerning co-presence ("the agent caught my attention"). In order to avoid user fatigue and to minimize experiment duration, only these two items were selected as indexes of affective experience. The items were selected because they represent the key elements of affective communication and co-presence. Finally, we asked the user to classify the agent's emotional expression using a five-alternative forced-choice scale ("The agent was… afraid/angry/happy/neutral/sad").

4.5 Design and Analysis

Participants undertook 4 blocks of 30 trials each. The glove used in the first block was counterbalanced between participants. In the three following blocks, the other glove was used. For each glove, trials were fully randomized across the 60 possibilities, which were obtained by orthogonally crossing the 2 types of actuators x 2 stimulus intensities x 5 expressed emotions x 3 animation versions.

Data analyses used three-way repeated measures ANOVAs with *emotional expression* (happy vs. angry vs. sad vs. fearful vs. neutral), *haptic technology* (C2 vs. pneumatic actuator vs. exciter vs. servo motor), and *stimulus intensity* (low vs. high) as factors as well as the self-report items (each of the five items as dependent measures). Following a validation check of the emotional expressions, we will first report on the effects of *haptic technology, stimulus intensity,* and *emotional expression* on *tactile ratings*, followed by the same effects on *affective ratings.* Finally, we will report how emotional recognition was affected. Degrees of freedom were adjusted using the Greenhouse-Geisser correction where violations of the sphericity assumption were detected.

5. RESULTS

To validate the agent's emotional expressions, we first analyzed the accuracy of the classifications. This showed a strong amount of consensus, with 81.5 ± 2.2% correct classifications. As shown in Figure 6, the accuracy was slightly below the reference data (taken from Ekman & Friesen, 1976, [9]), which was perhaps due to the somewhat shorter exposure duration (10 s in the reference data) or to memory interference from answering the four items between exposure and classification.

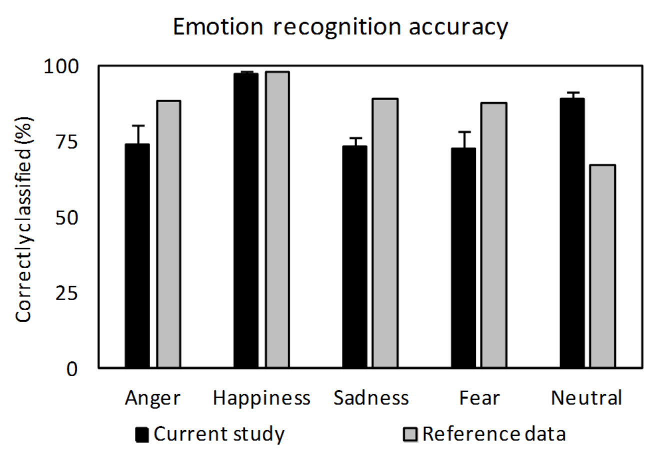

Figure 6. Emotion recognition accuracy. The gray bars represent reference data adopted from Ekman & Friesen (1976).

5.1 Tactile Judgements

To investigate how *emotional expression, stimulus intensity*, and *haptic technology* influenced touch perception, we first analyzed how these factors affected intensity rating. *Haptic technology* had a significant effect $F(3, 45) = 34.81$, $p < .001$, with the servo motor eliciting the highest ratings, and the C2 had the lowest effect. *Stimulus intensity* also had a significant effect $F(1, 15) = 37.00$, $p < .001$, with higher stimulus intensities following higher reported intensities. Emotional expression, however, had no significant effect on reported touch intensity F(4, 60) = 0.71, p > .5. The only significant interaction effect on reposted intensity was found between *stimulus intensity* and *haptic technology* F(3, 45) = 3.61, p < .03, with larger intensity effects in the haptic exciter technology.

Next, we used the same design to investigate whether *emotional expressions*, *haptic technology*, and *stimulus intensity* affected the naturalness of the touch. Again, *haptic technology* showed a significant main effect, F(3, 45) = 23.01, p < .001, with the servo motor rated most natural and the exciter rated least natural. However, neither s*timulus intensity,* F(1, 15) = 4.30, p = .06 nor *emotional expression*, F(4, 60) = 2.50, p = .08, was found to have a significant effect. No interaction effect was observed (*ps* > .2).

Since no effect of emotion on touch perception was found, we provide a short summary of how haptic technology was found to affect tactile judgements in Figure 7.

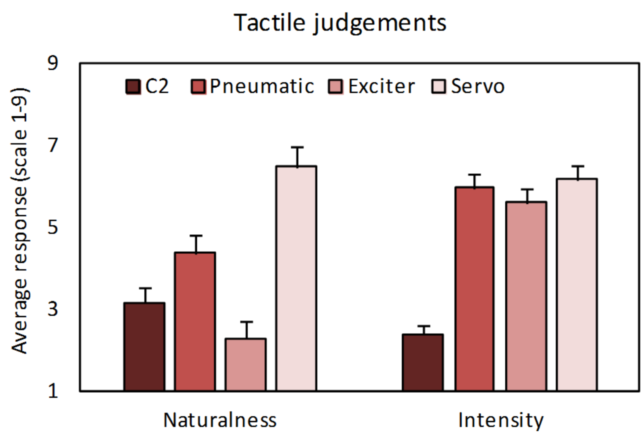

Figure 7. Self-reported touch intensity and naturalness of four haptic technologies.

5.2 Affective Judgements

Next, the same design was used to investigate how *emotional expression, stimulus intensity*, and *haptic technology* influenced participants' affective experiences. Regarding emotional interdependence, a main effect of *emotional expression* was found, F(4, 60) = 5.46, p < .02, with happy facial expressions eliciting the highest ratings and neutral ones the lowest (see Figure 8). Perhaps more interestingly, tactile parameters also affected the emotional interdependence, with both *haptic technology,* F(3, 45) = 8.50, p < .001, and *stimulus intensity*, F(1, 15) = 9.87, p < .01, having significant main effects. The higher ratings were for servo motors and higher intensities. No significant interaction was observed (*ps* > .2).

Similarly, for *co-presence*, the agent's *emotional expression* was found significant, F(4, 60) = 7.67, p < .005, as was the *haptic technology*, F(3, 45) = 8.77, p < .001, and the *stimulus intensity,* F(1, 15) = 16.54, p < .002, through which the tactile signal was communicated. No interaction was found significant (*ps* > .2). As with the preceding measure, happy emotional expressions elicited higher ratings, while neutral expressions had lower ratings. Similar to emotional interdependence, force feedback devices promoted co-presence better than vibrotactile touches. The servo motor in particular was found to improve attention toward the agent (see Figure 9).

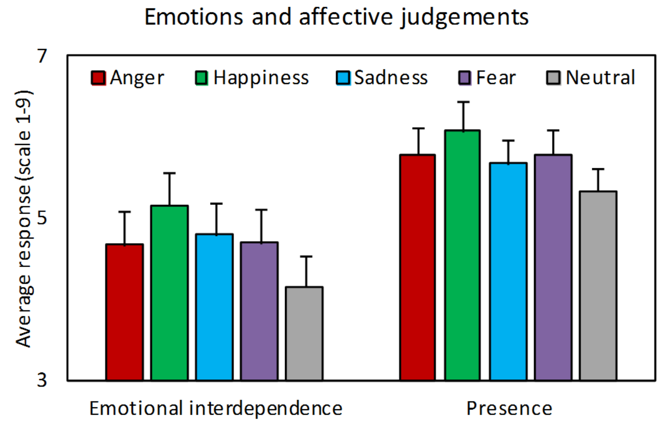

Figure 8. Judgments of emotional interdependence and co-presence as a function five emotional expressions.

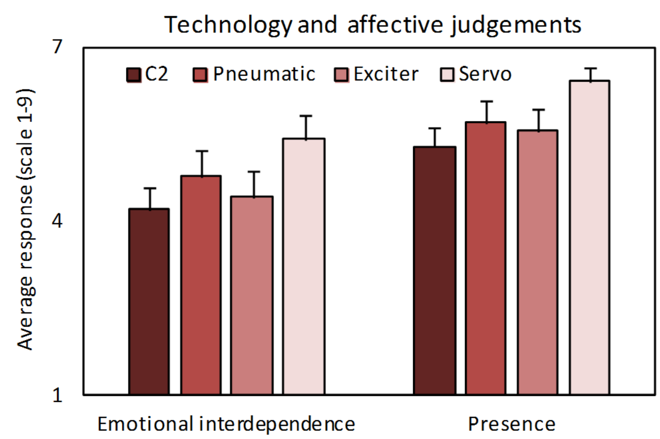

Figure 9. Judgments of emotional interdependence and co-presence in four haptic technologies.

6. DISCUSSION AND CONCLUSION

Using haptic technology to simulate the act of interpersonal touch has been shown to modulate human emotion and foster a sense of interpersonal connectedness [11]. Here we investigated whether certain haptic technologies are more suitable for affective communication. We found that judgements of touch intensity and naturalness varied as a function of haptic devices. Haptic stimuli delivered by vibrotactile actuators (the exciter and C2) were perceived as less natural compared to stimuli from force-feedback technologies. Servo motor-based haptic stimuli, in turn, were considered the most natural compared to all of the other devices. Likewise, the agent's facial expressions influenced affective experiences. Users were most influenced by the agent with a happy mood, and they had also greater sense of co-presence when interacting with the smiling agent.

When investigating the effect of haptic technologies on affective experience, we found that both the feedback type and intensity influenced the extent to which the users were influenced by the agent's emotion. Haptic technologies also affected the users' reports of co-presence. Interestingly, no significant interactions between emotions and haptic technologies were found to speak against the idea that different haptic technologies should be used with different emotions. However, we found that force feedback devices such as the one we used, which relied on a servo motor-driven elastic band, were overall more suitable for multimodal affective communication than vibrotactile devices. Finally, the more intense stimuli delivered by the servo device had a greater influence on the users' affective state and sense of co-presence.

As a potential limitation of the findings, it should be noted that the decision to integrate two technologies within each glove was not optimal in terms of the order of stimulus presentation. Because the gloves were changed only between blocks, it is possible that the judgements of tactile experiences were mainly based on comparisons between the pair of technologies presented within the same block. Thus, it is less surprising that no significant interactions were found between facial expressions and tactile judgements. However, we see no immediate reason that the limitation would have affected users' affective judgements. Moreover, the comparison between force feedback and vibrotactile stimuli remains valid at the level of feedback technology, as each glove always had one of each technology type.

In conclusion, the current findings clearly suggest that using mechanical force feedback systems instead of vibrotactile actuators can improve multimodal affective communication and increase the sense of social connectedness between users. We believe that several effects of mediated touch established by earlier studies (e.g. the virtual Midas Touch effect [14,31]) could also be enhanced through the use of force feedback. Another important aspect included in the current system is the embodied format of tactile communication [13]. In many earlier studies, participants received haptic stimuli without seeing the sender; removing the physical proximity from the touch makes it less clear to what extent the interaction can be seen as social or interpersonal. By contrast, in our system users were allowed to see the virtual agent who touched them. As demonstrated by the present findings, integrating visual feedback from the embodied agent into the haptic feedback can complement the affective effects of mediated touch, as it creates an illusion of physical proximity between the user and the virtual agent.

7. ACKNOWLEDGEMENTS
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8. REFERENCES
[1] Ahmed, I., Harjunen, V., Jacucci, G., Ravaja, N., and Spapé, M.M. Total Immersion: Designing for Affective Symbiosis in a Virtual Reality Game with Haptics, Biosensors and Emotive Agents. In *Symbiotic Interaction*. Springer, 2016.

[2] App, B., McIntosh, D.N., Reed, C.L., and Hertenstein, M.J. Nonverbal channel use in communication of emotion: How may depend on why. *Emotion 11*, 3 (2011), 603.

[3] Bailenson, J.N., Yee, N., Brave, S., Merget, D., and Koslow, D. Virtual interpersonal touch: Expressing and recognizing emotions through haptic devices. *Human–Computer Interaction 22*, 3 (2007), 325–353.

[4] Cabibihan, J.-J., Zheng, L., and Cher, C.K.T. Affective tele-touch. In *Social robotics*. Springer, 2012, 348–356.

[5] Courgeon, M., Buisine, S., and Martin, J.-C. Impact of expressive wrinkles on perception of a virtual character's facial expressions of emotions. *Intelligent Virtual Agents*, Springer (2009), 201–214.

[6] Courgeon, M., Martin, J.-C., and Jacquemin, C. Marc: a multimodal affective and reactive character. *Proceedings of the 1st Workshop on AFFective Interaction in Natural Environments*, (2008).

[7] Ekman, P. Facial expression and emotion. *American psychologist 48*, 4 (1993), 384.

[8] Ekman, P. and Friesen, W.V. Constants across cultures in the face and emotion. *Journal of personality and social psychology 17*, 2 (1971), 124.

[9] Ekman, P. and Friesen, W.V. *Measuring facial movement. Environmental psychology and nonverbal communication*. Human Sciences Press, San Francisco, 1976.

[10] van Erp, J.B. and Spapé, M.M. Distilling the underlying dimensions of tactile melodies. *Proceedings of Eurohaptics*, Citeseer (2003), 111–120.

[11] Gallace, A. and Spence, C. The science of interpersonal touch: an overview. *Neuroscience & Biobehavioral Reviews 34*, 2 (2010), 246–259.

[12] Guenter, B., Grimm, C.M., and Malvar, H.S. *Method and system for capturing and representing 3D geometry, color and shading of facial expressions and other animated objects*. Google Patents, 2000.

[13] Haans, A. and IJsselsteijn, W. Mediated social touch: a review of current research and future directions. *Virtual Reality 9*, 2–3 (2006), 149–159.

[14] Haans, A. and Usselsteijn, W.A. The virtual Midas touch: Helping behavior after a mediated social touch. *Haptics, IEEE Transactions on 2*, 3 (2009), 136–140.

[15] Hannig, G. and Deml, B. Efficient bimodal haptic weight actuation. In *Haptics: Generating and Perceiving Tangible Sensations*. Springer, 2010, 3–10.

[16] Hertenstein, M.J., Holmes, R., McCullough, M., and Keltner, D. The communication of emotion via touch. *Emotion 9*, 4 (2009), 566.

[17] Hertenstein, M.J., Keltner, D., App, B., Bulleit, B.A., and Jaskolka, A.R. Touch communicates distinct emotions. *Emotion 6*, 3 (2006), 528.

[18] Hoggan, E., Brewster, S.A., and Johnston, J. Investigating the effectiveness of tactile feedback for mobile touchscreens. *Proceedings of the SIGCHI conference on Human factors in computing systems*, ACM (2008), 1573–1582.

[19] Hoggan, E., Stewart, C., Haverinen, L., Jacucci, G., and Lantz, V. Pressages: augmenting phone calls with non-verbal messages. *Proceedings of the 25th annual ACM symposium on User interface software and technology*, ACM (2012), 555–562.

[20] Izard, C.E. The face of emotion. (1971).

[21] Jacucci, G., Spagnolli, A., Freeman, J., and Gamberini, L. Symbiotic interaction: a critical definition and comparison to other human-computer paradigms. In *Symbiotic Interaction*. Springer, 2014, 3–20.

[22] Jylhä, A., Hsieh, Y.-T., Orso, V., Andolina, S., Gamberini, L., and Jacucci, G. A Wearable Multimodal Interface for Exploring Urban Points of Interest. *Proceedings of the 2015 ACM on International Conference on Multimodal Interaction*, ACM (2015), 175–182.

[23] Lisetti, C., Nasoz, F., LeRouge, C., Ozyer, O., and Alvarez, K. Developing multimodal intelligent affective interfaces for tele-home health care. *International Journal of Human-Computer Studies 59*, 1 (2003), 245–255.

[24] Mathiak, K. and Weber, R. *The Fun of Gaming: Measuring the Human Experience of Media Enjoyment—Sub-*

project/partner no. 5 "The fMRI-based approach". Research proposal and study guide for the European Commission's NEST program. Coordination Dr. Niklas Ravaja, Helsinki School of Economics. Finland). Unpublished manuscript, RWTH Aachen University, Germany & Michigan State University, East Lansing, 2006.

[25] Mueller, F., Vetere, F., Gibbs, M.R., Kjeldskov, J., Pedell, S., and Howard, S. Hug over a distance. *CHI'05 extended abstracts on Human factors in computing systems*, ACM (2005), 1673–1676.

[26] Nakanishi, H., Tanaka, K., and Wada, Y. Remote handshaking: touch enhances video-mediated social telepresence. *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, ACM (2014), 2143–2152.

[27] Nam, C.S., Richard, P., Yamaguchi, T., and Bahn, S. Does Touch Matter?: The Effects of Haptic Visualization on Human Performance, Behavior and Perception. *International Journal of Human-Computer Interaction 30*, 11 (2014), 839–841.

[28] Robles-De-La-Torre, G. The importance of the sense of touch in virtual and real environments. *Ieee Multimedia 13*, 3 (2006), 24–30.

[29] Sherrick, C.E. A scale for rate of tactual vibration. *The Journal of the Acoustical Society of America 78*, 1 (1985), 78–83.

[30] Shimoga, K.B. A survey of perceptual feedback issues in dexterous telemanipulation. II. Finger touch feedback. *Virtual Reality Annual International Symposium, 1993., 1993 IEEE*, IEEE (1993), 271–279.

[31] Spapé, M.M., Hoggan, E.E., Jacucci, G., and Ravaja, N. The meaning of the virtual Midas touch: An ERP study in economic decision making. *Psychophysiology 52*, 3 (2015), 378–387.

[32] Takahashi, K., Mitsuhashi, H., Murata, K., Norieda, S., and Watanabe, K. Improving shared experiences by haptic telecommunication. *Biometrics and Kansei Engineering (ICBAKE), 2011 International Conference on*, IEEE (2011), 210–215.

[33] Van Erp, J.B. Guidelines for the use of vibro-tactile displays in human computer interaction. *Proceedings of Eurohaptics*, (2002), 18–22.

[34] Wang, R., Quek, F., Teh, J.K., Cheok, A.D., and Lai, S.R. Design and evaluation of a wearable remote social touch device. *International Conference on Multimodal Interfaces and the Workshop on Machine Learning for Multimodal Interaction*, ACM (2010), 45.

[35] Zmigrod, S., Spapé, M., and Hommel, B. Intermodal event files: integrating features across vision, audition, taction, and action. *Psychological Research PRPF 73*, 5 (2008), 674–684.