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Tactile Telepresence for Isolated Patients

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Abstract

For isolated patients, such as COVID-19 patients in an intensive care unit, conventional video tools can provide a degree of visual telepresence. However, video alone offers, at best, an approximation of a "through a window" metaphor—remote visitors, such as loved ones, cannot touch the patient to provide reassurance. Here, we present preliminary work aimed at providing an isolated patient and remote visitors with audiovisual interactions that are augmented by mediated social touch—the perception of *being touched* for the isolated patient, and the perception of *touching* for the remote visitor. We developed a tactile telepresence system prototype that provides a remote visitor with a tablet-based, touch-video interface for conveying touch patterns on the forehead of an isolated patient. The isolated patient can see the remote visitor, see themselves with the touch patterns indicated on their forehead, and feel the touch patterns through a vibrotactile headband interface. We motivate the work, describe the system prototype, and present results from pilot studies investigating the technical feasibility of the system, along with the social and emotional affects of using the prototype system.

Keywords: Mediated Social Touch, Telepresence, Tactile, Haptic

Index Terms: Human-centered computing—Human computer interaction (HCI)—Interaction devices—Haptic devices; Human-centered computing—Human computer interaction (HCI)—Interaction techniques—Gestural input; Human-centered computing—Accessibility—Accessibility systems and tools—; Applied computing—Life and medical sciences—Consumer health

1 Introduction

Human touch is a surprisingly powerful component of patient care [30]. There are physical impacts, psychological impacts, and spiritual impacts [7]. In situations where the patient is in pain, touch might be undesirable, however "being there through touch" can be very important. Even a simple reassuring touch has been recognized as an important intervention [10]. In the field of complementary and integrative medicine [2], the notion of *therapeutic touch* or *healing touch* is based on a philosophy that in addition to the physical dimension, humans have an energetic dimension that must be recognized during the healing process [1]. In some cases, such as the COVID-19 pandemic, patients must be isolated from visitors to avoid spreading diseases or compromising the patient. As a result, these isolated patients and their family members lose the mutual benefits of physical contact and touch.

While being touched is important for the patient, the act of touching is also valuable for those who care for or visit the patient, such as family members or other loved ones. For example, family members visiting patients in an intensive care unit (ICU) experience stress that can be reduced in several ways, including the ability to be physically close to the patient, feeling that they are helping the patient [24], and allowing visitors to witness and influence their loved one's comfort level first hand [21].

To address these issues, we have developed a tactile telepresence system prototype that enhances conventional video with the capability to sense and render two-dimensional (2D) touch patterns. As depicted in Fig. 1, our system comprises a *visitor-side* interface that is capable of sensing and transmitting 2D touch patterns to a *patient-side* interface that is capable of rendering the 2D touch patterns via a visual display and a vibrotactile headband device. For the visitor side, we made the decision to initially target a smartphone or tablet interface, as these are ubiquitously available. For the patient side, discussions with ICU nurses familiar with COVID-19 circumstances informed several considerations. For example, we decided on wired motors to reduce concerns about electromagnetic interference with medical equipment. We also seek to minimize the components on the patient, to reduce the intrusiveness of the tactile technology, and to mitigate cleaning and decontamination concerns. Because patients usually have many wires and tubes attached to their body, we considered appropriate touch-sensitive areas that are likely to be exposed, and decided to initially target the forehead. Not only is the forehead usually clear of wires and tubes, it is a place visitors would naturally touch the patient to offer reassurance [25]. In addition, a headband is a simple, familiar, reliable, and relatively unobtrusive means for affixing motors to the forehead.

Relatively few researchers have investigated mediated touch on the forehead [15]. This is possibly because people do not normally touch each others' foreheads outside of healthcare. As such, the circumstances surrounding isolated patients give rise to both a therapeutic need and a relatively new opportunity for mediated touch research. In addition, it turns out that humans generally have sub-centimeter sensitivity on the forehead and the ability to perceive 2D patterns. This motivated our use of a 2D array of vibrotactile motors and a 2D vibrotactile rendering algorithm, unlike most prior work, which have mainly focused on 1D arrays of vibrotactile motors.

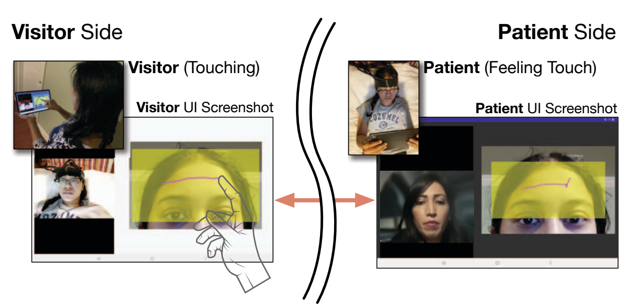

Figure 1: Diagram of our tactile telepresence system prototype, with examples of real users and the visitor/patient user interfaces.

In this paper, we first present and discuss our tactile telepresence system prototype, including the technical details of our visual and

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touch modalities. We then present a pilot study investigating a user's ability to recognize both 1D and 2D touch patterns generated by a user via the vibrotactile headband. Our results indicate that users can reliably perceive and recognize both 1D and 2D patterns. We also present a second pilot study investigating the affective qualities of our mediated social touch prototype. The results of this second pilot study indicate that our tactile telepresence system prototype can feasibly increase positive emotions (e.g., interested, excited, enthusiastic) while also decreasing negative emotions (e.g., upset, scared, irritable, nervous, afraid).

2 Related Work

In this section, we briefly discuss related work, including prior mediated social touch research, prior perceptual evaluations of tactile stimuli rendered on the head, the 1D limitations of previous head-based vibrotactile work, and known therapeutic aspects of touch.

2.1 Mediated Social Touch

Mediated social touch allows people to touch each other remotely through haptic devices and technologies [13]. Numerous devices have been developed and investigated for various mediated social touch purposes [16]. Several haptic devices have been developed to convey affectionate touches, such as arm squeezes [31]. Many other devices have focused on simply providing some form of virtual contact, such as touching the hand [5] or the upper arm [28]. While mediated social touch devices have been investigated for a broad range of body locations, little research has focused on the forehead [15]. Only recently, researchers have investigated using mediated social touch on the forehead to communicate spatial directions between users wearing head-mounted displays (HMDs) [8]. Our presented system furthers mediated social touch research on the forehead by investigating affectionate touches, such as the caring touch of a loved one.

2.2 Forehead-Based Perception of Tactile Stimuli

While few have investigated mediated social touch on the forehead, a number have investigated using tactile stimuli on the forehead to provide guidance and directions to the user. Bertram et al. [3] developed a tactile helmet for firefighters consisting of ultrasound sensors on the exterior to detect barriers and vibrotactile motors on the interior of the helmet to alert the user to the barriers. They informally found that users relied on their hands less while blindly navigating a corridor with the helmet than without. Using a headband of seven vibrotactile linear resonating motors, Kerdegari et al. [19] found that users could localize a tactile stimulus within 0.76 cm of its motor. In a similar study, de Jesus Oliveira et al. [9] found that users had a mean spatial precision of $M = 0.325$ cm on the frontal region of the head, which was significantly higher than their spatial precisions in the frontotemporal ($M = 0.615$ cm), temporal ($M = 0.726$ cm), and occipital ($M = 0.699$ cm) regions. Recently, Kaul et al. [18] also found that users have sub-centimeter precision ($M = 0.72$ cm) when localizing vibrotactile stimuli on the forehead.

In addition to vibrotactile stimuli, researchers have investigated other tactile stimuli on the forehead. Kajimoto et al. [17] developed a lightweight vision substitution system using a 32 x 16 grid of electrodes on the user's forehead to provide electrotactile patterns based on captured images. Peiris et al. [22] developed an HMD with thermal tactile stimulation, and found that users could recognize cold stimuli presented as directional cues with 89.5% accuracy and hot directional cues with 68.6% accuracy. More recently, Gil et al. [12] have explored the perception of in-air ultrasonic tactile cues on the forehead and face. They found that the center of the forehead led to optimal performance with a localization error of only 0.377 cm.

Altogether, these results clearly indicate that humans generally have high spatial acuity for localizing vibrotactile stimuli on their foreheads. This was one of the motivating factors for targeting mediated social touch on the forehead for isolated patients.

2.3 One-Dimensional Vibrotactile Arrays

Nearly all (if not all) of the prior work investigating vibrotactile stimuli on the head and forehead have focused on rendering vibrotactile stimuli using 1D arrays. Some researchers, such as Oliveira et al. [9] and Kaul et al. [18], have used dense 1D vibrotactile arrays, comprised of multiple, closely spaced motors, to investigate spatial perceptions about the head, such as the frontal, temporal, and occipital regions. Other researchers, such as Bertram et al. [3] and Kerdegari et al. [19], have used circular 1D vibrotactile arrays, comprised of sparsely spaced motors, to investigate perceptions of directional cues.

To the best of our knowledge, our work is the first to investigate a 2D vibrotactile array for rendering vibrotactile stimuli to the head in general, and the forehead in particular. Our research extends beyond simple spatial and directional perceptions, and instead, focuses on the user's perception of natural, 2D, continuous gestures, such as a loved one gently rubbing a patient's forehead.

2.4 Therapeutic Aspects of Touch

Touch has been effectively incorporated in patient contexts with a number of therapeutic effects on the patient, including reductions in pain, chronic inflammation, agitation, respiratory and heart rates, and improved mood [29]. Two main types of touch are accepted for use with patients, expressive or empathic touch, and instrumental or procedural touch [23]. Employing one type of instrumental touch, Suzuki et al. [26] performed a series of tactile massages to patients with dementia, which resulted in reduced levels of stress and aggressiveness. The researchers used an effleurage massage technique, comprised primarily of circular massage motions intended to reduce pain. These circular motion techniques are 2D in nature, and motivate the potential value of a 2D vibrotactile device in patient-visitor environments. The areas of touch and the relationships of those providing touch are both important aspects of touch, as discussed in the literature. Consistent with the tactile interface being presented, the literature supports the head and forehead as one of the most frequently touched body parts [25]. In addition to nurses and other clinicians, loved ones of the patient can also provide such massage techniques [20].

Visitor restrictions due to COVID-19 may result in touch hunger and detrimental health outcomes for residents of long-term care facilities [4]. While immediate responses to this imposed isolation have included online technologies, such as Facebook or WhatsApp, these interventions alone may be difficult to comprehend by those with cognitive dysfunction [4]. The use of video for patient-provider interactions dramatically increased within days of the institution of pandemic restrictions, and the US government actually relaxed various telemedicine restrictions [6]. Video has also shown to be an effective means for interactions between loved ones and isolated patients, even for palliative care—specialized care for people with a serious illness. It has helped mitigate the sense of patient isolation and can allow family members to see their loved one's comfort level for themselves [21]. The ability of remote family members or other loved ones to "touch" and visually interact with isolated patients will allow them preserve the socio-emotional components of their relationship, which has benefits for both the patient and the loved ones [11]. The same mechanisms could also be used for provider-patient interactions when the provider cannot easily or safely enter the patient's ICU room.

Collectively, these findings provide strong evidence for the need to provide video enhanced with mediated social touch, in which family members or providers can remotely provide effleurage-style strokes to the forehead with synchronous audiovisuals to comfort the isolated patient and themselves.

3 TACTILE TELEPRESENCE SYSTEM PROTOTYPE

As shown in Fig. 1, our tactile telepresence system prototype involves a visitor-side interface, a network interface for relaying mediated social touches, and a patient-side interface. We depict the system with real images, including photos of users in the visitor and patient roles, and screenshots from their respective tablet interfaces.

The visitor side (left in Fig. 1) provides remote family members and visitors with video and audio from the patient, and a touch-input interface for conveying touch patterns on the isolated patient's forehead (e.g., rubbing or other patterns that might be associated with reassurance or comfort). The patient side (right in Fig. 1) provides the patient with video and audio from the visitor, and tactile sensory stimuli of visitor-initiated touches on their forehead via a tactile headband comprising a grid of vibrotactile motors. The network interface is responsible for transmitting video and audio, in both directions, and visitor-initiated touch gestures from the visitor interface to the patient interface. We employed Samsung Galaxy Tab S5e tablets for both interfaces. The moderately sized tablet (24.5 cm × 16.0 cm) has a 10.5-inch screen with a resolution of 2560 × 1600 pixels. The device is also relatively lightweight at 14.11 oz.

In the following sections, we discuss both the audiovisual and touch modalities of our tactile telepresence system prototype. We will only briefly describe the audiovisual modality, which comprises both audio and video, as it is relatively straightforward, while we will describe the touch modality in more detail.

3.1 Audiovisual Modality

Live video and audio streaming is integrated into both the visitor and patient interfaces using the Vonage Video API. Both the visitor and patient publish live video streams using the front camera of the tablet to a session, and subscribe to each others live video streams. On the visitor tablet interface, the visitor views live video of the patient. On the patient tablet interface, the patient views live video of the visitor.

The user interface layout for both the visitor and patient tablet interfaces are the same. The layout is divided into two frames, each frame approximately half the length of the tablet's screen, and the layouts are maintained in landscape mode. The left frame displays a live video stream while the right frame displays a static image of the patient with a semi-transparent rectangle covering patient's forehead to represent the mediated social touch area (see Fig. 1). The use of two frames minimizes viewing obstructions of the live-video stream when drawing touch patterns.

3.2 Touch Modality

Here we describe the processing associated with the touch modality, including the visitor-side touch input (left in Fig. 1) and the patient side tactile rendering on the headband (right in Fig. 1).

3.2.1 Visitor-Side Interface (Touching)

The visitor-side interface is responsible for detecting, recognizing, and forwarding the touch patterns performed by the visitor on the tablet interface to the patient-side interface, as shown in Fig. 1.

For the visitor-side interface, we developed an Android application using Android Studio. The application overlays a semi-transparent yellow "region of touch" rectangle over the static image of the patient's forehead. This 10.5 cm × 5.5 cm rectangle represents the valid region for performing touch input to relay to the isolated patient. The visitor-side interface supports both single-touch and multi-touch capabilities. Currently, the application can process up to ten fingers simultaneously touching the tablet within the region of touch. The application also renders the visitor's touch patterns as path "drawings" within the region of touch, with each finger involved in the touch pattern represented by a different color. Both the visitor and patient see this rendering of the visitor's touch patterns.When a finger is lifted up, the path representing that finger is removed.

Since the patient-side haptic motors are arranged in a 4 × 2 grid on the headband (see Sect. 3.2.3), each touch point coordinate (x,y) on the semi-transparent yellow rectangle is normalized to float values ranging $[0,4.0]$ on the x-axis and $[0,2.0]$ on the y-axis. This provides a normalized margin of space of 0.5 units around the motors, i.e., the top-left motor is located at the normalized coordinate position of $(0.5,0.5)$. We provide this margin because our vibrotactile rendering algorithm supports touch patterns within the corresponding physical margins of the patient-side headband (see Sect. 3.2.3).

Any touch points outside of the semi-transparent yellow rectangle are considered invalid touch points and are reset to a negative coordinate point of $(-1.0,-1.0)$, which the patient-side interface will recognize as an inactive touch point because it is outside of the valid normalized range. Similarly, when the input is multi-touch in nature, any touch point that is no longer active due to the visitor lifting a finger will also be reset to the negative coordinate point.

3.2.2 Network Transmission of Touch

In order to relay touch gestures from the visitor-side interface to the patient-side interface, we chose to transmit touch point data through a User Datagram Protocol (UDP) connection between the visitor-side and patient-side interfaces. We chose to use the UDP protocol over the Transmission Control Protocol (TCP), in order to prioritize real-time transmission and delivery of the touch gestures and because an undelivered set of touch points will likely be less perceptible than a delayed set of touch points.

3.2.3 Patient-Side Interface (Feeling Touch)

The patient-side interface allows patients to feel the perception of touch through vibrotactile motors by receiving and processing the touch patterns from the visitor-side. Once the visitor draws a gesture on their tablet, that touch pattern is sent to the patient's tablet. The patient is able to see these touch patterns as "drawings" on the tablet (see Fig. 1). These gestures are then sent to the Raspberry Pi from the patient's tablet, which renders the touch pattern to the corresponding motors on the tactile headband. The patient-side interface should be portable and comfortable for the patient to use. With the tactile headband, isolated patients should be able to perceive and recognize a visitor's intended touch gestures.

Hardware A Raspberry Pi 4 was used to control the patient interface. It is a highly efficient, low-cost, small computing device that consists of General Purpose Input/Output (GPIO) pins, that can drive the vibrotactile motors. Because the vibrotactile motors' operating current is greater than the maximum supply current of the GPIO pins, we used a ULN2803A Darlington Transistor Array. This channel driver consists of eight channels that can drive all the motors using GPIO signals from the Raspberry Pi. Each channel effectively amplifies the current from the GPIO pins to drive the motors. An external 5V DC battery supply was used to power the the driver and the vibrotactile motors.

The patient-side tactile headband consists of eight 10 mm × 3 mm eccentric rotating mass motors, with a rated speed of 12000 RPM. The far-ranging speed and compact size of the motors provided the most comfort and perceived intensity. All of the motors are arranged in a 4×2 grid with a horizontal spacing of 3 cm and vertical spacing of 2 cm. Velcro adhesive-back squares were used to attach each motor to the headband, which was constructed out of Hook & Look tape. This allowed flexibility in the positioning of the motors.

Tactile Rendering Software To ensure the tactile headband would produce spatially continuous tactile sensations for the user, we implemented the Syncopated Energy Algorithm [27], a real-time vibrotactile rendering algorithm that determines the intensity that each motor contributes to simulate the touch point. We use each 2D touch point sent from the visitor-side interface to compute the amplitudes of the closest phantom motors. We do this using the 1D formulas in Equation (1) and Equation (2), first in the horizontal direction (closest left and right motors) and then in the vertical direction (closest above and below).

$$A_N = TC_N\sqrt{1-\beta} \quad (1)$$
$$A_{N+1} = TC_N\sqrt{\beta} \quad (2)$$

In Equation (1) and Equation (2), β is the distance between A_N and the touch point's respective 1D coordinate, normalized by the distance between A_N and A_{N+1}; T is the intensity of the touch point; and C_N is a per-motor weight determined from a perceptual calibration of the tactile headband. The default weight is $C_N = 1.0$, however during calibration we found that a weight of $C_N = 0.8$ for the inner four motors (columns 2 and 3) produced a more perceptually consistent tactile sensation across the entire headband. While there are many plausible explanations for the differences between the inner and outer forces (hence the differences in weights), we speculate that the dominant causes are the shared forces from the neighboring motors in the interior, and larger catenary forces (tensile forces acting along the fabric) on the edges due to the tension of the fabric wrapped around the head.

The calculated amplitude A_N for each motor is rendered using pulse width modulation. If an motor is more than 1 grid unit away from the touch point, that motor is automatically rendered with an amplitude of $T = 0$. Whenever the user lifts a finger off of the visitor-side interface, the patient-side interface recognizes it as an inactive touch point and will automatically render the motor's contributing amplitude as $T = 0$.

The visitor interface has multi-touch capability, and can send coordinates for up to 10 touch points (one for each finger). When the visitor uses such multi-touch gestures, the Syncopated Energy Algorithm computes each motor's contributing amplitude for all of the touch points. Then, the maximum amplitude across all touch points is used for rendering the motor's amplitude value. For multi-touch gestures, each finger's pattern is visually rendered onto to the screen of the patient-side tablet in different colors.

4 Tactile Recognition Feasibility Experiment

We carried out a pilot study of our prototype system to test the ability of a single user, a 50-year-old female, to perceive a variety of patterns of touch rendered on her forehead. The overall process, which comprised two steps, is reflected in Fig. 2. In the first step, an experimenter drew a pattern in the "region of touch" rectangle on the visitor tablet, which was then rendered for the subject via the vibrotactile headband. We refer to this as the vibrotactile rendering (VR) step. In the second step, the subject—who was wearing the tactile headband with her eyes closed—was asked to draw the pattern that she felt on her forehead, using the patient interface. We refer to this as the subject rendering (SR) step. A subjective comparison of the results of the VR and SR steps offers an indication of the prototype's ability to render touch patterns, and the subject's ability to recognize such mediated social touches.

We evaluated touch patterns in four categories: single points, swiping, closed shapes, and multitouch. The collection was chosen to span the types of patterns that might occur naturally when reassuring or comforting a patient. In Fig. 3, we include samples of continuous swiping motions, closed shape patterns, and multitouch patterns. In each sub-figure we included translucent representations of the locations of the eight headband motors along with connecting grid lines. We did this for both the VR and SR plots, so that both the pattern's proximity to the motors would be clear for both the vibrotactile rendering and the subject's perception of it. We also encoded the temporal aspect of the touch pattern using color: the start of the pattern is blue, the end of the pattern is orange, and the intermediate portion is a smooth transition between these, passing through yellow in the middle. Note that the subject appeared to correctly perceive the shape closures.

5 Affective Telepresence Pilot Study

We carried out a pilot study with seven individuals, three males and four females, ranging from the ages of 16-50, to investigate the social and emotional affect when using the tactile telepresence prototype system. Our university's Institutional Review Board (IRB) reviewed and approved our pilot study.

In the study, we simulated an isolated patient in a hospital room setting with bright lights and a bed for them to lay on. First, the subject, referred to as the patient, would enter the room devoid of others, lay in the bed, and wear the vibrotactile headband. After they put on the headband, they would complete the Positive and Negative Affect Schedule (PANAS) to measure their positive and negative affect before the system was used. Then, they would use the patient-interface tablet to receive a live video feed of a family member, referred to as the visitor, in a remote location, and to see the visitor's touch patterns rendered in the semi-transparent "region of touch" over the image of the forehead. The visitor's tablet displayed a live video feed of the patient along with the visual representation of the patient's forehead and semi-transparent "region of touch". The patient and visitor would then hold a five-minute conversation via the tactile telepresence prototype, in which the visitor asked the patient how they were feeling while delivering comforting touch patterns by drawing in the "region of touch". After this conversation, the subjects answered questions about their experience on an open-ended questionnaire, rated their levels of social presence using the Harms and Biocca Social Presence Survey [14], and completed the PANAS again to measure their emotional affect after this experience.

Table 1: Harms and Biocca Social Presence Survey Results

Social Presence Question	Mean	Standard Deviation
1. I noticed my visitor.	1.29	0.49
2. My visitor noticed me.	1.00	0.00
3. My visitor's presence was obvious to me.	1.14	0.38
4. My presence was obvious to my visitor.	1.14	0.38
5. My visitor caught my attention	1.14	0.38
6. I caught my visitor's attention.	1.43	0.54
7. I could tell how my visitor felt.	3.00	0.82
8. My visitor could tell how I felt.	1.71	0.76
9. My visitor's emotions were not clear to me.	2.57	0.79
10. My emotions were not clear to my visitor.	4.00	0.58
11. I could describe my visitor's feelings accurately.	2.86	0.69
12. My visitor could describe my feelings accurately.	1.29	0.49

5.1 Quantitative Results

Subjects completed Harms and Biocca's Measure of Social Presence survey, specifically the co-presence and perceived affective understanding questions (see Table 1). The co-presence questions (questions 1-6 in Table 1) intend to measure the extent to which the subject is aware of the visitor and vice versa. The perceived affective understanding questions (questions 7-12 in Table 1) measure the subject's ability to understand the visitor's emotions and their perception of the visitor's ability to understand their emotions. The participants were instructed to rate each statement on a scale from 1 (Strongly Agree) to 5 (Strongly Disagree), which is recorded in Table 1. The scores indicated that the subject generally felt the co-presence of their visitor and perceived to have their visitor's attention. While the subjects' perceived that their visitor could describe their emotions

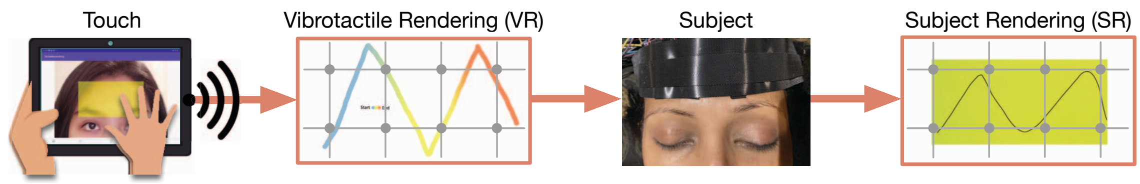

Figure 2: The overall tactile recognition evaluation process, comprising two steps: the input and vibrotactile rendering of a touch pattern (VR), and the subject-drawn rendering of the perceived pattern (SR).

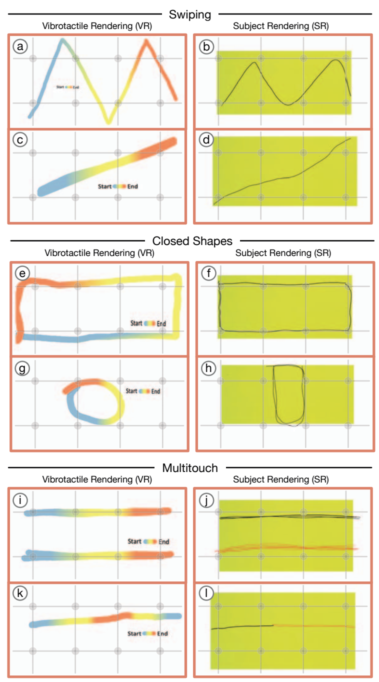

Figure 3: Sample actual and subject-interpreted patterns representing (a)–(d) continuous swiping motions, (e)–(h) closed shape patterns, and (i)–(l) multiple fingers moving simultaneously (multitouch).

Table 2: PANAS Survey Results. Bold typeface and an asterisk (*) indicate emotions supporting the affective qualities of our prototype.

	Pre-Study	**Post-Study**	**Δ**
Emotion	**Mean**	**Mean**	**Mean**
Interested[1]	2.43	4.43	2.00
Distressed	2.00	1.14	-0.86
Excited[1]	1.71	3,.00	1.29
Upset[1]	2.29	1.00	-1.29
Strong	2.00	1.57	-0.43
Guilty	1.14	1.00	-0.14
Scared[1]	2.43	1.00	-1.43
Hostile	1.71	1.14	-0.57
Enthusiastic[1]	1.43	2.86	1.43
Proud	1.57	2.14	0.57
Irritable[1]	3.00	1.14	-1.86
Alert	2.14	2.57	0.43
Ashamed	1.29	1.00	-0.29
Inspired	1.43	1.71	0.29
Nervous[1]	2.43	1.14	-1.29
Determined	1.71	1.57	-0.14
Attentive	2.14	2.86	0.71
Jittery	2.14	1.29	-0.86
Active	1.57	2.43	0.86
Afraid[1]	2.00	1.00	-1.00

and tell how they felt, they perceived that they could not describe or understand their visitor's emotions. As seen in questions 7 and 11 in Table 1, the participants recorded that they felt neutrally about them. This disconnect could be attributed to the subjects' inability to reciprocate the touch gestures that they received, so they could not quite understand what their visitor was feeling.

Before and after the tactile telepresence experience, participants completed the PANAS questionnaire. This questionnaire consists of 20 words that describe different feelings and emotions, in which the subject had to indicate the extent they felt that emotion. The scale ranges from 1 to 5, with 1 representing that the emotion was felt very slightly or not at all to 5 representing that the emotion was extremely felt. The means of the pre-study and post-study results and the differences between them are reported in Table 2. It was observed that the positive emotions of the subjects (e.g., enthusiasm, excitement, alertness, and activeness) increased after using the device. On the other hand, their negative emotions (e.g., nervousness, fear, upset, and irritability) decreased after the tactile telepresence experience.

5.2 Qualitative Results

The open-ended questionnaire asked the subject to describe their physical, emotional, and social sensations throughout the study. Before the tactile telepresence experience, we primed our subjects to achieve an emotional state that would be expected of being alone in an ICU (e.g., lonely, scared, nervous). In contrast to this negative affect state, our subjects described experiencing positive emotions due to the tactile telepresence experience. One subject specifically stated that they felt ”scared and anxious” before using the vibrotactile headband and that they felt ”calm and relaxed” afterwards. Many of the subjects expressed the perception that their family member was in the room with them, despite being remote. One subject stated that ”it felt like I was in the presence of someone even though I was alone”, and another subject stated that they ”felt connected” to their visitor. These qualitative results support the mediated social touch benefits of our tactile telepresence system.

In addition to social presence, subjects also reported positive perceptions of the vibrations themselves. In particular, several subjects perceived the touch patterns as massage-like. One subject described the vibrations as if they were ”massaging my forehead and made it very relaxing”. Another subject described the sensation as if ”it massaged my head nicely and felt soothing”. Several of the subjects indicated that the experience reduced their stress and improved their moods. Hence, these qualitative results clearly indicate that our tactile telepresence system is capable of providing massage-like touch patterns, like the effleurage touch massage technique demonstrated by Suzuki et al. [26] as resulting in reduced levels of stress and aggressiveness for patients with dementia.

6 Conclusions and Future Work

In this paper, we have presented the design and prototype for a tactile telepresence system that provides a remote visitor with a tablet-based, touch-video interface for conveying touch patterns on the forehead of an isolated patient. The isolated patient can see the remote visitor, see themselves with the touch patterns indicated on their forehead, and feel the touch patterns through a vibrotactile headband interface. We carried out two pilot studies. The results of our first pilot study indicate that users can reliably perceive and recognize touch patterns rendered to the vibrotactile headband. The results of our second pilot study indicate that this tactile telepresence system prototype has the potential of socially connecting isolated patients with remote family members.

Future improvements to this system include better placement of the motors in the center of the headband for improved perception, using a softer fabric for the base of the headband, testing the latency of the system, and making the tactile headband more compact and portable by omitting the breadboard. We have also identified interested partners at a local hospital, where we hope to eventually carry out formative tests with actual patients.

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