SqueezeBands: Mediated Social Touch Using Shape Memory Alloy Actuation

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Mediated social touch technologies aim to transmit the sense of touch between two or more physically distributed partners. Previous work in CSCW has focused mostly on vibrotactile actuation, though there is also significant recent interest in exploring a wider variety of haptic actuation modalities. In this paper, we explore Shape Memory Alloys as a novel means for constriction and heat activation. We demonstrate the feasibility of this approach by implementing the SqueezeBands system, which augments social gestures over videochat with haptic actuation. We describe an evaluation of the system with 57 pairs of participants, collaborating on tasks either high or low emotional salience. Our results demonstrate that SqueezeBands encourage greater and more diverse demonstrations of touch and that they may be particularly appropriate for easing mental and physical demand in high emotion tasks. We end with a discussion of the opportunities and challenges in leveraging Shape Memory Alloy actuation for mediated social touch.

CCS Concepts: • **Human-centered computing** → Collaborative and social computing → *Collaborative and social computing devices* • **Hardware** → Communication hardware, interfaces and storage → Tactile and hand-based interfaces → *Haptic devices*

KEYWORDS

Mediated Social Touch; Haptic Interaction; Computer-Mediated Communication; Shape-Memory Alloys

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1 INTRODUCTION

Humans use touch to communicate friendliness, affection, support, playfulness, and more [32]. Just as technologies like videochat allow users to communicate by transmitting video and audio, Mediated Social Touch (MST) is a technological paradigm that focuses on allowing people to transmit touch [6]. Mediated Social Touch is a relatively nascent area of investigation, with few ideas taken beyond the conceptual design

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stage, few systems developed to leverage modalities other than the vibrotactile, and relatively few systems investigated through quantitative comparisons with alternatives [18,21]. Contributing to system design and evaluation in this area may support affective communication in contexts like connecting family [11], long-distance relationships [56], and social support in health and wellness [8]. While MST is a long way from achieving the nuance of real human touch, there may be opportunities to augment existing interactions with communication technologies with haptic actuation to increase the benefits of such exchanges.

Fig. 1. 57 pairs of participants performed high and low emotion tasks together: (a) paired participants sat at tables separated by a wall panel; (b) duplexed projector-camera surface allowed for mediated social touch through overlapping video, as well as (c) provided a shared work space; (d) SqueezeBands responded to touch gestures with squeezing and heat, (e) controlled through an Arduino USB connection; (f) the video screen showed a standard face-to-face video chat view and feedback window.

In this paper, we propose and investigate a novel technology for MST haptic actuation. Our primary contribution is in exploring a novel technical approach of using Shape Memory Alloys (SMA) for constriction and heat actuation for MST in a collaborative context. We demonstrate the feasibility of this approach by implementing the SqueezeBands prototype, which augments touch gestures directed at a videochat partner with haptic actuation (see Fig. 1). We describe the development process and implementation of this system with sufficient detail to support other researchers in adapting SMA for future MST technologies. Our secondary contribution is a user study of this system, undertaken to address the following research questions:

- **RQ1:** How does the addition of SqueezeBands affect social presence, task load, and touch gestures attempted in a collaborative task?
- **RQ2:** How does the emotional salience of the collaborative task influence SqueezeBands' effect on social presence, task load, and touch gestures attempted?

We begin by situating our contributions in terms of the previous work conducted in this area. We discuss the SqueezeBands system, including its design and implementation, to support others in using SMA in future investigation. We describe the setting, participants, and procedure of our empirical investigation, which included 57 pairs of participants from the Minnesota State Fair. We report our findings, which show this system's capacity for encouraging touch interaction and its benefits in reducing mental and physical task load in high emotion tasks. We conclude with a discussion of our findings that examines the broader opportunities and challenges for Shape Memory Alloy actuation in MST.

2 RELATED WORK

Touch-based communication is an emerging domain [18]. We compare and contrast previous technical approaches to leveraging the sense of touch in CMC.

2.1 Haptics in Communication

Many investigations of haptics in communication do not focus on supporting or replicating social touch. These included haptic awareness mechanisms, haptic feedback in collaboration, haptics as a channel for information signal, and affective haptics. Both of the first two approaches focus on offloading information onto the haptic channel as a strategy for managing information overload, signaling availability state, and increasing awareness in collaboration (e.g., [3,6,13,19,49,50]). The third approach focuses on the use of touch as a channel to transmit information and investigate human ability to interpret such signal. These studies may focus on transmitting information through a pre-established code [10,38] or may develop and validate alternative alphabets for information transmission such as tactons [7], tactile icons [24], or haptic phonemes [17]. The fourth common approach in haptic communication focuses on investigating affective expression [16]. Frequently, these studies operationalize emotion as a set of distinct states to be encoded using haptic affordances provided, asking one participant to communicate an emotion by manipulating a haptic device and another to identify that emotion from a given set (e.g., [29,30,52]). The common thread in these investigations is haptic output as an additional channel for transmitting information.

2.2 Mediated Social Touch (MST)

In contrast, mediated social touch concerns itself not with the transmission of information signal through haptic channels but rather with reestablishing the social benefits of touch in remote communication contexts. One common thread of work focuses on enhancing existing communication channels (e.g., phone call, videochat) by incorporating an expressive haptic channel. These are not meant to replicate existing touch gestures but rather create a new vocabulary for social interaction. One classic example of this approach is InTouch [5], a networked device that synchronized state across two locations (i.e., pushing a local rod, moved a remote rod). In a more recent CSCW example, Singhal et al. [51] communicated touch by transmitting the flexing of an "input" glove as a vibrotactile sensation in an "output" glove. Similarly, Park et al. [46] incorporated haptic feedback into an off-the-shelf mobile phone system, allowing participants to tap the back of the phone while speaking, vibrating the partner's phone in patterns such as "tickling," "slapping," and "tapping" [46,47]. Many of these approaches have focused on vibrotactile output modalities as they provide relatively good resolution and variation for creating an intimate vocabulary.

An alternative strategy focuses on supporting existing forms of social touch, such as shaking hands, hugging, etc. For example, Nakanishi et al. [43] investigated a robotic arm for transmitting a handshake while videoconferencing. Wang et al. [57] built a haptic pressure sleeve that could be controlled by pressure on the remote participant's phone, allowing a storyteller to "squeeze" a participants arm at emotionally-intense moments in a story. Holding hands at a distance has been investigated both through Peltier pump haptic gloves [20] and through overlapping projection [58]. Many researchers looked at haptic hugging as a possible interaction. For example, DiSalvo et al. [12] considered the idea from a critical design perspective, Tsetserukou [54] built a vibrotactile vest, Cha et al. [9] developed a vibrotactile jacket, and The et al. [53] built air pressure pajamas for children. One thing to note is that while the vibrotactile modality is represented in these investigations, there is also a significant effort to incorporate alternative modalities. Overall, this is a fecund area of research, particularly for systems work leveraging new modalities and new methods of actuation.

2.3 Comparing and Contrasting Approaches

Haptics in communication and MST approaches for leveraging the sense of touch in computer-mediated communication differ in three major ways. First of all, they differ in priorities—communication haptics focus on touch as a channel for information transmission, while MST focuses on touch as a mechanism in building and reinforcing social connections. Second, they differ in the role of physical haptic activation. Haptic communication technologies by definition include some level of physical actuation (e.g., vibration, heat). MST technologies may or may not include haptic elements in how they attempt to transmit the experience of social touch. In fact, there are multiple investigation that report that the sensation of touch can be simulated though sensory illusions by taking advantage of the dominance of visual senses to the interpretation of stimuli (e.g., [4,31,40]). For example, the act of holding hands could be mediated with haptics (e.g., the Peltier pump in the YourGloves system [20]) and without haptics (e.g., overlapping projection in the ShareTable system [58]). Lastly, MST approaches (particularly ones focused on supporting existing touch vocabularies rather than creating new ones), seem to prioritize diverse modalities of actuation beyond just the vibrotactile. In this work, we contribute an exploration of a novel approach of leveraging Shape Memory Alloys in wearable bands to transmit constriction and heat.

3 SYSTEMS

In order to investigate the feasibility and potential benefits of Shape Memory Alloy haptic actuation, we implemented SqueezeBands and compared it to an existing MST system. We describe both systems below.

3.1 Experimental System: SqueezeBands

The primary contribution of this work is in exploring the potential for SMA actuation in MST technologies through the development of SqueezeBands. The SqueezeBands system consists of a two sets of haptic bands for each user to wear while communicating with a partner via videochat. Activated in response to particular gestures, the bands communicate touch through pressure and heat using Shape Memory Alloy haptics. We describe the development of these shape memory alloy haptic bands in sufficient detail to support replication.

3.1.1 Shape Memory Alloy Haptics. The compression and heat output of SqueezeBands is implemented using Shape Memory Alloys (SMAs). SMAs are an appealing choice for on-body compression applications. SMAs undergo solid-state phase transformations when heated, resulting in macro-scale shape changes that can be strategically tailored to produce a variety of actuation modes [35,37]. Specifically, SMAs formed into fully-compacted, tightly wound springs have been shown to produce significant forces (>7N) [27] and significant stroke lengths (up to 75% reduction in initial, deformed length) [26] in a form factor that is conducive to garment integration (millimeter diameter spring helices). These actuators respond to an applied current which induces resistive heating; typical off-the-shelf SMAs transform between 40°C and 150°C [27] and cycle on the order of 30-60 seconds [28], though these characteristics are highly dependent on the specific alloy chosen, the post-processing steps implemented, the magnitude of power applied, and the specific system architecture. When used in compression garment applications, significant pressures—up to 34.3 kPa (257 mmHg)—can be generated dynamically by modulating an applied current [25]. To date, on-body compression using dynamic SMA spring actuators has been studied for aerospace applications [25], anxiety treatment for sensory processing disorder (SPD) [14], and to combat symptoms related to orthostatic hypotension [15]. In this study, we apply SMA compression to mediated social touch.

For this purpose, we used off-the-shelf Flexinol SMA wire[2] (0.012” diameter, 70°C nominal activation temperature), modified to create low-spring index spring actuators. We followed an accepted manufacturing protocol [27] which includes two steps: forming the desired spring shape at room temperature (by wrapping the SMA around a 0.025” diameter stainless steel wire core), and annealing the spring form at high temperature (450°C for 10m) to set the memory state. The resulting springs were integrated into the physical design of the haptic bands.

[2] http://www.dynalloy.com/tech_data_wire.php

3.1.2 Physical Design. The compression and heat output of SqueezeBands is implemented using Shape Memory Alloys (SMAs). SMAs are an appealing choice for on-body compression applications. SMAs

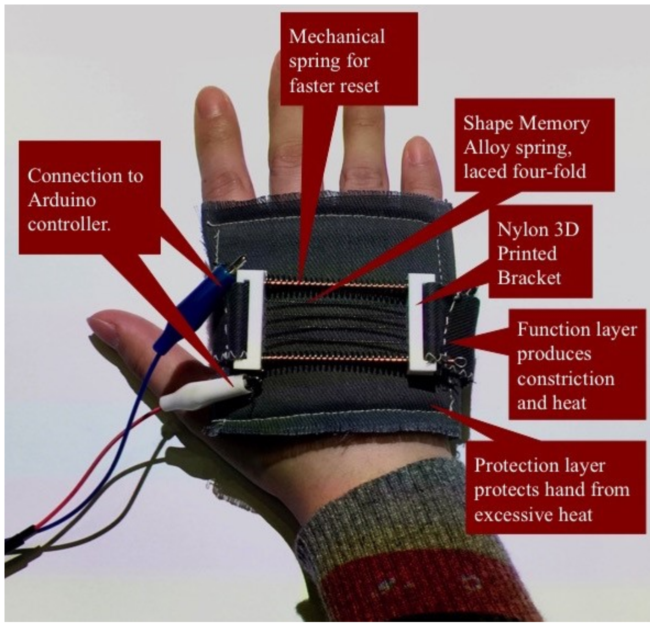

Fig. 2. The components of a single SqueezeBand. All participants who used the experimental system were outfitted with a SqueezeBand on their dominant hand and another on their upper arm.

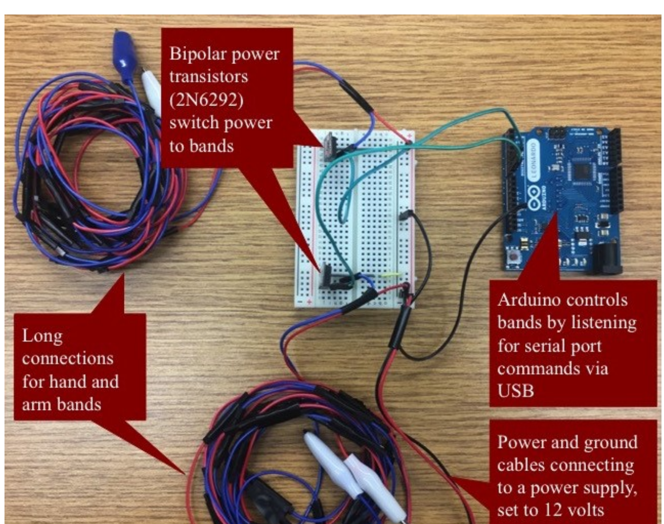

Fig. 3. The circuit setup for controlling the SqueezeBands, with power to each band controlled

undergo solid-state phase transformations when heated, resulting in macro-scale shape changes that can be strategically tailored to produce a variety of actuation modes [35,37]. Specifically, SMAs formed into fully-compacted, tightly wound springs have been shown to produce significant forces (>7N) [27] and significant stroke lengths (up to 75% reduction in initial, deformed length) [26] in a form factor that is conducive to garment integration (millimeter diameter spring helices). These actuators respond to an applied current which induces resistive heating; typical off-the-shelf SMAs transform between 40°C and 150°C [27] and cycle on the order of 30-60 seconds [28], though these characteristics are highly dependent on the specific alloy chosen, the post-processing steps implemented, the magnitude of power applied, and the specific system architecture. When used in compression garment applications, significant pressures—up to 34.3 kPa (257 mmHg)—can be generated dynamically by modulating an applied current [25]. To date, on-body compression using dynamic SMA spring actuators has been studied for aerospace applications [25], anxiety treatment for sensory processing disorder (SPD) [14], and to combat symptoms related to orthostatic hypotension [15]. In this study, we apply SMA compression to mediated social touch.

In the function layer, aramid fabric is used to resist heat and lower friction. We laced a singular SMA spring (see section 3.1.1 for description) four-fold through two custom Nylon 3D printed brackets, creating a cartridge structure with 4 parallel actuators. Each end of this spring is clipped to an Arduino-connected breadboard, which controls its actuation. Fig. 3 provides a detailed view of this setup. Each breadboard is connected to a power supply providing 12V of power. An Arduino Leonardo sends a signal to one or both of two bipolar power transistors to switch power to one or both of the bands. The Arduino receives signal via USB serial port directly from a commodity computer used for videochat. When the current is switched on, the function layer SMA spring constricts and heats up. After 2.5 seconds, the band is fully compressed, though the user begins to feel pressure as early as 1 second after the current is applied. When the current is switched off, the SMA spring stops constricting. To accelerate the reset process in the "off" state (from the typical 30 seconds), we added a mechanical tension coil spring to the band. After 10 seconds, the band is reset to original status, though the user begins to feel an easing of the pressure as early as 3 seconds after the current is turned off. A round copper tube is placed through the mechanical spring to support it, so the mechanical spring will not bend when it is extended or compressed.

In the protection layer, both neoprene and aramid fabric are used protect the user from excessive heat. The layer also distributes pressure across a larger area of the hand or upper arm. This layer includes an adjustable Velcro strap to allow the bands to be tightly positioned on the hand and upper arm of participants across a wide range of body sizes.

3.1.3 Selected Gestures and Wizard of Oz. We developed SqueezeBands to supplement videochat as communication channel. Previous work has discussed that during videochat in the home, people may rely on "over-exaggerated gestures" [34] and "hugs, pats, kisses" [33] towards their partner as forms metaphorical touch. Inspired by this previous work, we chose to focus on detecting particular gestures towards a remote participant on the screen and augmenting these gestures through haptics. While the eventual goal is automated detection of gestures, for our study we wanted to evaluate the feasibility of SqueezeBands themselves without confounding this question with the accuracy of gesture detection. To guarantee high gesture detection accuracy for the study, we chose to follow a Wizard of Oz approach of having a trained experimenter secretly observe participant actions and trigger appropriate system responses (a Bluetooth keyboard was used to signal the computer regarding any of the supported gestures).

SqueezeBands supported five types of gestures in this investigation, chosen because previously work has identified them as relevant gestures in video-mediated communication and because they provided a wide variety of gestures for diverse relationship types. The five gestures chosen were handshake (e.g., explored in [44]), high-five (e.g., explored in [41]), hug (e.g., observed in [2]), shoulder pat (e.g., observed in [42]), and holding hands (e.g., observed in [58]). The researcher observed the following protocol regarding the detection of these gestures (we refer to the two dyadic partners as A and B, where either partner may be A or B):

- Handshake (activate A-hand-band and B-hand-band): activated when both A and B extend a curved hand towards the camera and perform a shaking motion. Bands are activated for as long as the gesture continues.

- High-Five (activate A-hand-band and B-hand-band): activated when both A and B extend an open hand towards the camera and perform a high-five motion. Bands are activated for a 3-second interval only.
- Hug (activate A-hand-band and B-arm-band): activated when A extends two arms toward each side of the computer monitor and leans forward to preform a hugging motion towards B. Bands are activated for as long as the gesture continues.
- Shoulder Pat (activate A-hand-band and B-arm-band): activated when A extends one arms toward the side of the computer monitor on which B is wearing their arm band and preforms a patting motion. Bands are activated for as long as the gesture continues.
- Holding Hands (activate A-hand-band and B-hand-band): activated when both A and B place their hands on analogous locations of their tables. Bands are activated for as long as the gesture continues. Note that this gesture is not possible with standard videochat, but only with the control system we describe in 3.2, which provides a shared tabletop display.

The experimenters conducting the WoZ portion of the study were asked to act as a gesture detector without error correcting. In other words, if both participants stretched in a way similar to a high-five or if two participants had their hands in the same are of the table but seemingly without the intention to hold hands, the system would still trigger. Handholding was the only gesture where such accidental activation was observed in the study. Since multiple gestures may lead to the same type of physical actuation (e.g., a hug or a shoulder pat both feel like a squeezing of the arm band to the recipient), participants were required to use the addition visual context of the interaction to understand what gesture was being enacted.

There were two times in this study when we had to deviate from the protocol described above, both in the handholding gesture. In both cases, participants' hands overlapped on the table surface for a significant length of time without them intending to actually hold hands. In those situations, the bands were activated for over 3 minutes at a time and the system began to overheat. In both of those situations we deactivated the bands temporarily to allow them to cool for the participants' safety.

3.2 Control: ShareTable

In order to understand whether SqueezeBands could contribute positively to a mediated social touch interaction, we compared them to a non-haptic MST system. We selected the ShareTable system as a point of comparison because previous investigations have shown that participants have appropriated this kind of a setup for mediated social touch [58]. In that previous investigation, participants spontaneously interpreted placing hands in the same area of the table (thus having the remote hand projected on top of the local one) as "holding hands." The ShareTable employs a duplexed projector-camera (pro-cam) system for transmitting touch through overlapping video and providing a shared workspace. This system (including the video echo cancelation approach) is described in detail in others' publications [55], so we only provide a brief overview of the system's design and capabilities here. The system consists of a synchronous media space using the HP Sprout SDK and C# WPF as a development platform. It uses the WebRTC protocol in a Chromium Embedded Framework to transfer video, audio, and data between setups over peer-to-peer communication [59]. The media space infrastructure consists of two Chromium instances running on each HP Sprout. One instance provides the interpersonal space by transmitting video and audio from the front-facing camera (i.e., typical videochat setup). The second Chromium instance creates the duplexed pro-cam shared workspace by sending video from downward-facing cameras to be projected on the remote tabletop. Fig. 4 documents the spaces and signaling between the spaces in the system. In the feasibility study described below, we compare user experiences with the ShareTable system alone to the ShareTable used in combination with SqueezeBands.

4 METHODS

We tested SqueezeBands with 57 pairs of participants to address the following research questions:

- **RQ1:** How does the addition of SqueezeBands affect social presence, task load, and touch gestures attempted in a collaborative task?

- **RQ2:** How does the emotional salience of the collaborative task influence SqueezeBands' effect on social presence, task load, and touch gestures attempted?

This work was part of a larger study of MST (i.e., the data set was also used to validate a new questionnaire for MST systems [39]), however we focus only on the factors relevant to SqueezeBands here.

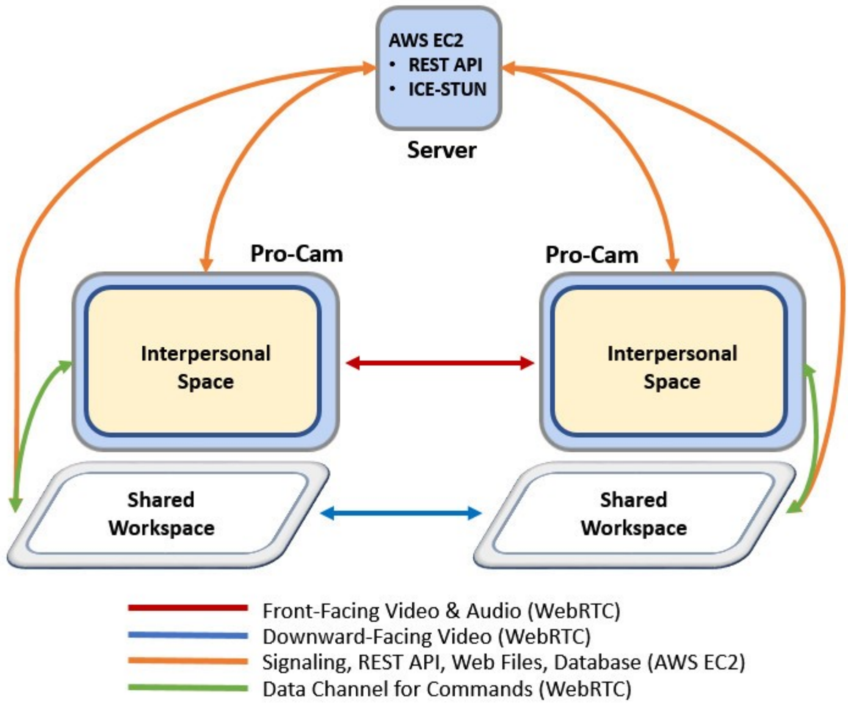

Fig. 4. The ShareTable system includes a standard video/audio interpersonal space and a duplexed pro-cam overlapping video space, implemented using WebRTC on the HP Sprout system.

4.1 Setting and Participants

The study took place at the Minnesota State Fair, in the Driven to Discover Research Facility on fair grounds. Fig. 1 shows the participant setup, with each participant using an identical system to communicate while separated by a wall panel. Each participant wore noise-cancelling headphones and spoke into a microphone.

Participants were recruited for the study as they passed by the Driven to Discover Research Facility on the fair grounds. Members of the research team also advertised the study on the U of M Stage and encouraged Fair attendees to join. The average age of the participants was 36.8 years old (SD = 16.7) and 53% were female (47% male). We recruited participants travelling with friends or family members (29 pairs) or matched participants without partners to another stranger during this study (28 pairs). Pairs were randomly assigned to one task and one technology condition as specified below.

4.2 Tasks, Conditions, and Procedure

This study represented a 2x2 between-subjects factorial design. All participants were randomly assigned to perform one of two 10-minute collaborative tasks with one of two MST systems.

The first factor investigated was the system used by the participants (we refer to this as the "tech" condition). Thirty participant pairs used the ShareTable system described in section 3.2. The other 27 pairs used the ShareTable with the SqueezeBands system described in section 3.1.

Given that social touch is particularly influenced by the specifics of context and task [32], we also wanted to examine the role that emotion may play in experiences with the SqueezeBand. We hypothesized that social touch may be more appropriate and more important when emotion is involved. To incorporate the emotional level of the task as a factor in the evaluation, we chose two tasks that were functionally similar but involved different levels of emotion:

- Low Emotion: discuss a scenario about a fictional company (pet store specializing in cat products) and collaboratively design and draw a new logo for it.
- High Emotion: discuss a struggle from childhood (e.g., moving, failing a test) and collaboratively design and draw a poster to help children facing the same struggle.

The Minnesota State Fair provided us with an opportunity to validate this instrument with a demographically diverse group. An unfortunate trade-off was that the task needed to be relatively short to be appropriate for the State Fair context. We considered a number of possible tasks deciding to focus on a collaborative design task as one that could be appropriate between both strangers or known pairs, one that required substantial collaboration, and one that could feasibly be accomplished in a 10-minute session. We also acknowledge that there is a fair amount of individual difference in the perception of emotion. Given this diversity, we strived to recruit a large sample to allow random assignment to reduce the influence of any single person's perception on the task.

After random assignment, 31 pairs completed the low emotion task together while 23 pairs completed the high emotion task. An important point is that known pairs and stranger pairs were assigned to conditions in a balanced way that evenly distributed them across technology and task types. Thus, there were 15 stranger and 15 known pairs who tried the ShareTable alone and 14 stranger and 13 known pairs who tried the ShareTable with SqueezeBands. We strived for this balanced assignment to ensure that the participant relationship did not introduce systematic bias to the comparison between the two systems.

All participants completed IRB-approved consent forms. Each pair received a demonstration of the system, including having them to try out a sample touch gesture with each other ("high five" in the SqueezeBands condition, "low five" overlapping their hands on surface in the ShareTable only condition). We also explained each of the other types of touch in both conditions (see section 3.1.3 for list). For example, a "handshake" in the either condition would involve holding one's hand towards the front facing camera and moving it up and down. Each pair was then given 10 minutes to work towards their assigned task. After this time was complete, each participant filled out several questionnaires about their experience and had the opportunity to debrief with the research team. Participants received a drawstring University-branded backpack for their help.

4.3 Metrics and Analysis

We collected a number of metrics from each of the participants. During the task, we video recorded all interactions, focusing on the gestures that the participants made to their remote partners (3 pairs' video was lost due to technical difficulties and they were excluded from analysis). After the task, we collected participant metrics on two validated questionnaires:

- NASA Task Load Index (NASA-TLX) [23]– a validated measure of workload (e.g., effort and difficulty) of a particular interaction. We converted scales to seven point Likert-type scales (instead of 100 point scales) to address constraints of our data collection software. We refer to this measure as "task load" in this paper.
- Networked Minds Measure of Social Presence (NMMSP) [22]– a validated measure of social presence (i.e., the degree to which participants feel like they are "together") in networked interactions. We refer to this measure as "social presence" throughout this paper.

After the study, we segmented and reviewed each of the videos. We developed three broad categories for coding the role that touch played in each of the interactions (we refer to this measure as "attempted touch" throughout this paper):

- No Touch (0) – the participants did not attempt any touch interactions beyond the initial demo.
- Some Touch (1) – the participants took part in at least one intentional touch interaction or explicitly noted unintentional touch.
- Significant Touch (2) – the participants took part in more than one intentional touch interaction.

We examined the effect of the technologies and the interaction between task and technology on the three measures above. The data was analyzed using Multivariate General Linear Models in SPSS at a .05 significance level. We discuss our specific hypotheses and results for each of these measures in the next section.

4.4 Method Limitations

Our study design led to some trade-off and limitations. We elected to run this study at a large public event in order to attract diverse participants who are unaffiliated with our university. Unfortunately, the trade-off was that we had very limited time with each participant. The study design was limited to between-subjects and each pair was limited to only a 10-minute task. Both the ShareTable and the SqueezeBands systems were quite novel to participants. It is possible that a sustained interaction with both systems would lead to more nuanced results that better account for novelty effects. We encourage this kind of investigations as future work; however, the short task was sufficient for a feasibility study of this novel system.

Table 1. Descriptive statistics of each condition and dependent variable.

Tech Condition	**Task Condition**	**# Pairs**	**Avg. Social Presence** (out of 7)	**Avg. Task Load** (out of 7)	**Med. Touch Attempted** (ordinal: 0, 1, or 2)
ShareTable	Low Emotion	17	4.67 (SD = 0.53)	2.81 (SD = 0.82)	Med = 2 (IQR = 1)
	High Emotion	13	4.95 (SD = 0.40)	2.52 (SD = 0.76)	Med = 1 (IQR = 2)
SqueezeBands + ShareTable	Low Emotion	14	4.82 (SD = 0.38)	2.98 (SD = 0.97)	Med = 2 (IQR = 0)
	High Emotion	14	4.86 (SD = 0.44)	2.71 (SD = 1.16)	Med = 2 (IQR = 0)

5 RESULTS

All descriptive statistics are reported in Table 1 and inferential results in Tables 2 and 3. We formed the following hypotheses a priori of conducting the investigation:

- **H1a:** SqueezeBands + ShareTable will score higher than ShareTable alone on measures of social presence. **(Result: not confirmed)**
- **H1b:** There will be an interaction between task type and technology type used, with Squeezebands + ShareTable scoring higher on measures of social presence than ShareTable alone for high emotion tasks. **(Result: not confirmed)**
- **H2:** There will be an interaction between task type and technology type used, with SqueezeBands + ShareTable scoring lower on measures of task load than ShareTable alone for high emotion tasks. **(Result: confirmed)**
- **H3a:** Participants will attempt more touch interactions in the SqueezeBands + ShareTable conditions than with the ShareTable alone. **(Result: confirmed)**
- **H3b:** There will be an interaction between task type and technology type used, with Squeezebands + ShareTable leading to more touch attempts in high emotion tasks than ShareTable alone. **(Result: not confirmed)**

We expand on each of these hypotheses, results, and describe *post hoc* analyses below.

Table 2. Between-subjects tests of main effect of tech and interaction effects of tech/task.

Factor	Dependent Variable	Between-Subjects Test	Partial Eta Squared
Tech	Social Presence	p = 0.721	η = 0.001
	Task Load	p = 0.231	η = 0.014
	Touch Attempted	p < 0.000***	η = 0.352
Task * Tech	Social Presence	p = 0.181	η = 0.017
	Task Load	p = 0.049*	η = 0.037
	Touch Attempted	p = 0.077	η = 0.030

Table 3. Between-subjects post-hoc tests of the task/tech interactions effects on each task load subscale.

Factor	Task Load Subscale	Between-Subjects Test	Partial Eta Squared
Task*Tech	Mental Demand	p = 0.021*	η = 0.048
	Physical Demand	p = 0.002**	η = 0.086
	Temporal Demand	p = 0.271	η = 0.011
	Performance	p = 0.339	η = 0.008
	Effort	p = 0.073	η = 0.029
	Frustration	p = 0.554	η = 0.003

5.1 Social Presence

We hypothesized that those participants who used the SqueezeBands system would report higher degrees of social presence than those using only the ShareTable. While the difference was in the expected direction (ShareTable M = 4.79, SqueezeBands M = 4.84), it was not statistically significant. We also hypothesized that there may be an interaction effect with task type, with high emotion tasks benefiting more on the social presence measure than low emotion tasks. However, no such statistically significant interaction was present. Overall, it seems that at least for short tasks, the SqueezeBands do not support greater social presence than the ShareTable system alone. Further investigation is required to ascertain whether this is a result of the specific technology or whether longer interactions would lead to different outcomes.

5.2 Task Load

While we did not think that there would be a main effect of technology on task load overall, we hypothesized that it would be easier (i.e., lower task load) to perform a high emotion collaborative task with the additional haptic support provided by the SqueezeBands system. Indeed, we observed a statistically significant interaction ($p = 0.049$, $\eta = 0.037$) in the expected direction. Fig. 5 shows that SqueezeBands have higher overall task load that the ShareTable alone for low emotion tasks but lower task load in high emotion tasks. This shows that this kind of haptic support may be unhelpful in low emotion tasks (perhaps because of additional distractions introduced), but may be more helpful in high emotion tasks.

To investigate this interaction effect in more detail, we conducted a post-hoc analysis examining the interaction effect on each of the sub-scales of the NASA-TLX measure (see Table 3). We observed that the overall interaction effect was due to statistically significant interactions on the "Mental Demand" ($p = 0.021$, $\eta = 0.048$) and "Physical Demand" ($p = 0.002$, $\eta = 0.086$) subscales (see Table 3 and Fig. 5). This is evidence that having the opportunity to communicate touch through haptic feedback in high emotion tasks moderated the mental demand required to complete such tasks and the physical demand of performing and responding to touch gestures.

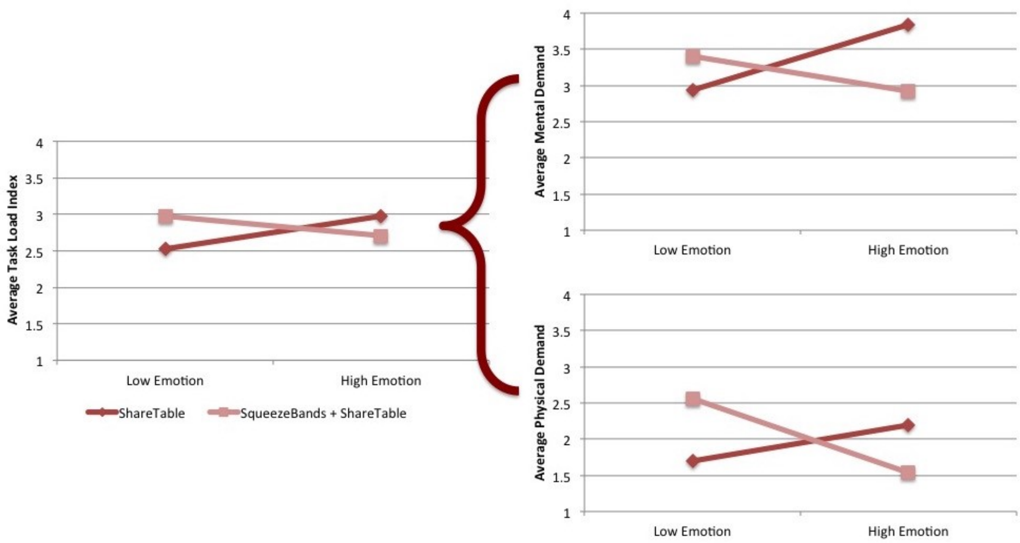

Fig. 5. The tech/task interaction plots for the overall task load and the mental and physical demand subscales. Note that on all of these scales, higher response corresponds to MORE demand or load (i.e., lower number = easier to perform).

5.3 Touch Attempted

We hypothesized that it would be easier and more compelling to communicate touch using the SqueezeBands system, so we would observe more touch interactions attempted. Indeed, we observed a statistically significant ($p < 0.000$) effect of technology on attempted touch, with a substantial effect size ($\eta = 0.352$). Looking at the descriptive statistics (Table 1), we noted that in both types of tasks SqueezeBands had the median of 2 the interquartile range of 0—meaning that every pair who used the SqueezeBands attempted substantial touch using the system.

We also hypothesized an interaction with task, since touch may be more appropriate between users engaged in a high emotion task. We did not observe a statistically significant interaction. From more detailed analysis of the attempted gestures, we noted that participant pairs found appropriate gestures to use even in low emotion tasks (e.g., high five to celebrate completing the task).

Table 4. Types of touch attempted in each condition, showing the total number times this form of touch was attempted by all pairs.

Tech	Task Emotion	High or Low-5	Handshake	Shoulder Pat	Hug	Holding Hands
ShareTable	Low	1	0	0	0	5
	High	1	0	1	0	5
SqueezeBands + ShareTable	Low	7	0	5	0	6
	High	15	2	7	1	4

In retrospect, we considered that our *a priori* selection of touch attempted as an ordinal variable might have been particularly sensitive to novelty effects in this study. To achieve a more nuanced understanding of the attempted touch, we conducted a post-hoc analysis examining the specific touch gestures participants tried with each technology.

Table 4 reports the number of times a particular gesture was attempted by pairs in a particular condition. It is clear that pairs attempted the largest variety of gestures in the SqueezeBands high emotion condition (the only conditions were handshake or hug were attempted). It is also clear that overall participants attempted more touch gestures in the SqueezeBands condition. A Chi-square test between the technology conditions is statistically significant (p = 0.006).

6 DISCUSSION

In this section, we interpret the results of our finding and discuss the opportunities and challenges for SMA haptic systems in CSCW and related communities.

6.1 Feasibility of SqueezeBands for MST

In our feasibility evaluation, we looked at how the addition of SqueezeBands affected user experience when added to a non-haptic MST synchronous communication system (ShareTable). Overall, the findings were mixed. Compared to ShareTable alone, participants were more likely to attempt touch gestures towards their communication partner. While the effect of this finding was quite significant, we anticipate that it may have been at least partially due to novelty effects and particular demand characteristics of being asked to use a haptic system during a communication session. However, it may have also reflected the participants' general enthusiasm about this kind of a system (certainly a number of them mentioned appreciating this interaction when being debriefed). Another variable where we found expected differences was in the interaction between task and technology on the perceived task load. Examining the specifics of this difference more closely, we saw that SqueezeBands eased mental and physical demand on high emotion tasks. Of course, the converse is that they may have been distracting on low emotion tasks without adding anything to the interaction. This may also echo the results of previous tabletop collaboration research, which focused on low-emotion collaborative tasks and found that haptic feedback was less helpful than visual one [13]. By comparing both high and low emotion tasks, our work points to the importance of considering haptic systems in context of the specific tasks for which they are deployed.

However, other hypotheses were not confirmed. We anticipated that the SqueezeBands would increase reported social presence, but found no statistically significant difference. It is possible that a difference would become more apparent during more sustained interaction with the system (as a 10-minute task is fairly short). But it is also quite possible that this kind of a "gesture amplifying" haptics approach to MST has minor or no effect on social presence compared to a non-haptic MST system.

One other aspect to note about the feasibility of this approach is its performance throughout the study. Overall, the SqueezeBands system was robust and reliable through use with dozens of diverse participants over the course of four days in a fairly hectic setting (the Minnesota State Fair). SqueezeBands have few moving parts, reducing the number of possible problems with the system. This may compare favorably to systems that have to employ arrays of vibrotactile elements (e.g., [51]) to simulate touch. However, while the system performed as designed, we did notice at least two cases where the current design of the system may have presented a safety danger to the user (see section 3.1.3). Additional components and logic may have to be added to ensure user safety if used outside of a controlled setting.

Overall, while not all of our initial hypotheses were confirmed, we found that there were some benefits of the SqueezeBands prototype and that it provided sufficient validation of the feasibilities to continue exploring Shape Memory Alloys as an MST actuation approach.

6.2 Opportunities and Challenges for SMA MST

There have been several explorations of Shape Memory Alloys in HCI and related fields. However, most of these applications have focused on the needs of an individual user. For example, uncoiled SMA wire has been used to create animated origami as a form of art [48], to animate physical artifacts as a form of ambient information display [45], or to change the shape of clothing to support people with disabilities in putting on clothing without help [36]. However, coiled SMA for on-body compression has not been explored as a mechanism for mediated social touch. Our investigation provides the first feasibility study in this domain. While we discovered that SqueezeBands were feasible, there are a number of opportunities and challenges for future explorations of the SMA approach.

There are a number of challenges in using SMA actuation for on-body haptics and mediated social touch. First there is the challenge of safety. In our study there were two cases where we needed to break research protocol to prevent the system from overheating and to ensure participant safety (see section 3.1.3). Any on-body SMA system deployed outside of a controlled setting must integrate safety sensors and employ automated shutdowns to prevent heat actuation outside of specific safety limits. Detecting, properly responding to, and gracefully recovering from unsafe states are important considerations for future SMA MST work.

The second challenge in leveraging SMA for MST systems is due to the relatively slow cycling speeds of SMAs. By adding a mechanical tension coil spring to our prototype (see section 3.1.2), we were able to reduce reset speed significantly but were unable to reduce it to below 10 seconds without significantly affecting the pressure produced. This is quite slow given the immediate nature of many types of social touch. For example, in a real high five, contact occurs for only a fraction of a second. Our system was only able to provide a "metaphorical" high five experience. With our current approach, SMA haptics are best suited for slower and more lingering forms of touch rather than slaps, pokes, or other momentary gestures. However, there may be alternative arrangements of SMA wire that may provide more immediate feedback and reset. For example, recent work in Material Engineering has focused on knitting multiple SMA wires into two-dimensional architectures that allow more precise control over actuation and resetting [1].

Despite these challenges, there are several unique opportunities provided by SMAs for mediated social touch. In order to trigger an SMA to return to its annealed shape, heat must be generated and applied to the SMA (typically by passing a current through it). In many SMA applications this generated heat is just an unwanted side effect of the system. However in Mediated Social Touch applications, generated heat serves as an additional modality that can help communicate a sense of touch and a lingering trace of a touch after it has occurred. This may be particularly compelling for forms of affectionate touch that linger beyond the momentary: holding hands, placing a hand on somebody's arm, cheek, lower back, or leg. Our systems explored very specific locations for touch that we viewed as appropriate to the specific tasks in our study, but there are many other opportunities left to investigate. In a similar vein, we only explored compression as physical actuation, but a number of MST applications may benefit from other forms of physicality. For example, an on-body interface containing strips of fabric with embedded SMA coils which contract when activated may provide a sensation similar to a finger trailing up a stretch of skin or slow stroking. We encourage other MST researchers to explore alternative modalities of SMA actuation. In exploring these novel forms of touch, we believe that qualitative methods would be particularly salient—the lived experience of lingering touch is perhaps better subjectively explained rather than objectively measured.

7 CONCLUSION

Mediated Social Touch technologies seek to enhance remote relationships by allowing parties to transmit touch across distance. While most previous investigations have focused on vibrotactile haptics, we contribute an exploration of Shape Memory Alloy as a novel approach to constriction and heat actuation. To demonstrate the feasibility of SMA in MST technologies, we implemented the SqueezeBands system, which adds constriction and heat actuation to common "exaggerated gestures" in videochat (e.g., metaphorical hugging, high fives). We investigated this system in an experimental study with 114 participants. We sought to understand how the addition of SqueezeBands affected social presence, task load, and gestures attempted in two collaborative tasks of different emotional salience. Our investigation contributed two empirical insights: (1) the addition of SqueezeBands to a non-haptic MST technology led users to attempt more and greater variety of gestures; and (2) the addition of SqueezeBands helps reduce physical and mental work load in high emotion tasks (while conversely being detrimental in low emotion ones). Through this substantial deployment process, we were also able to articulate advantages of SMA (e.g., silent, reliable) as well as challenges that would need to be resolved in further explorations (e.g., safety, reset speed). We hope that this work is the first of many to consider SMA as novel approach to haptic actuation in MST contexts.

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