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Int. J. Human-Computer Studies 65 (2007) 376–387

International Journal of Human-Computer Studies

www.elsevier.com/locate/ijhcs

Communicating emotion through a haptic link: Design space and methodology

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Abstract

Communication of affect across a distance is not well supported by current technology, despite its importance to interpersonal interaction in modern lifestyles. Touch is a powerful conduit for emotional connectedness, and thus mediating haptic (touch) displays have been proposed to address this deficiency; but suitable evaluative methodology has been elusive. In this paper, we offer a first, structured examination of a design space for haptic support of remote affective communication, by analyzing the space and then comparing haptic models designed to manipulate its key dimensions. In our study, dyads (intimate pairs or strangers) are asked to communicate specified emotions using a purely haptic link that consists of virtual models rendered on simple knobs. These models instantiate both interaction metaphors of varying intimacy, and representations of virtual interpersonal distance. Our integrated objective and subjective observations imply that emotion can indeed be communicated through this medium, and confirm that the factors examined influence emotion communication performance as well as preference, comfort and connectedness. The proposed design space and the study results have implications for future efforts to support affective communication using the haptic modality, and the study approach comprises a first model for systematic evaluation of haptically expressed affect.

Keywords: Haptic communication; Affect; Evaluation methodology; Early design

1. Introduction

The world is becoming increasingly connected through travel and cheap, fast communication technology. Paradoxically, we also find ourselves more distant physically from those we are emotionally close to; and despite many technological options, it can be difficult to communicate affect over a distance.

People sharing the same space use touch to convey diverse and subtle social messages (e.g. Collier, 1985). It is a complex and expressive medium: many norms and meanings are defined culturally, and they often depend on the gender and relationship of those involved. However, this channel is generally not available in remote contexts, and it is reasonable to believe that its well-designed addition could provide an appropriate path for expressive remote nonverbal communication.

Haptic (touch) research includes the design of interactions employing devices through which virtual physical models can be felt, just as we display to our visual sense with graphical displays. In a remote haptic communication scenario, otherwise separated individuals interact with one another through a pair of haptic displays, which are themselves connected via a computer running coupled virtual physical models. There have been several intriguing schemes to support person-to-person haptic interaction, including (Brave and Dahley, 1997; Fogg et al., 1998; Chang et al., 2002).

In our view, it is time to set aside device-specific questions and systematically consider the design space encompassing both the virtual model and those using it. For users to successfully communicate affect to one another, the coupled virtual model must afford the expression of affective concepts, and thus central design issues relate to the nature of signal encoding. A telephone

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doi:10.1016/j.ijhcs.2006.11.006

works by encoding and decoding audio signals such that the output is a close approximation of the input, but for haptic devices it is not obvious what a good mapping from a user's gesture to the forces or motion perceived at the other end would be. Infinitely many possibilities exist. However, we know little about how to approach this as a design problem, and there is no literature of evaluative measures for haptic communication of affect to guide exploration of the space.

In the work described here, we explored two important and coupled questions. First, what are the design space's most influential parameters and how should they be used? Secondly, how can we evaluate different haptic interactions with respect to their support of affective expression? To this end, we identified and analyzed a useful design space, then prototyped and compared several interactions occupying targeted positions within it. We devised an evaluative method for these interactions which combined objective and subjective measures of a collaborative, improvisational task: users haptically conveyed and identified specified emotions with a partner, while we recorded their identification performance, confidence and aesthetic/social reaction to the experience.

We devised our experiment methodology to relate success in affect communication to manipulations of an affect design space, rather than to assess the absolute value proposition of the haptic channel itself. However, the data we obtained using this principled approach also suggests that a purely haptic link can indeed support communication of affect. Together with the comparative results, this has important implications for future interaction design in support of haptic affective communication.

2. Related work

In co-located situations, touch conveys many social messages including hostility, sexual interest, nurturance and dependence, affiliation and the level of intimacy in a romantic relationship (Collier, 1985). This "crucial aspect of most human relationships" (Knapp and Hall, 2002) is the first sense to develop (Montague, 1986) and the only reciprocal sense, combining action and perception (Frank, 1957). Another form of nonverbal communication in co-present situations is the use of interpersonal distance, which has been found to vary with many factors including sex, age, culture, relationship, topic, interaction setting, physical and personality characteristics, attitude and emotional orientation (Knapp and Hall, 2002). Given the role of touch and interpersonal distance in co-present communication, it would seem that computer-mediated touch interaction, possibly supporting a concept of personal space, is a good candidate for supporting *remote* communication of affect as well.

The haptics research community has considered mediated affective human-to-human communication in a lightweight way: several devices have been built but there has been little structured analysis. InTouch (Brave and Dahley, 1997) was a provocative conceptual prototype suggesting a shared object manipulated simultaneously by two people (each user moved a hand across a personal set of rollers while feeling her partner's motion through the motion of her own) and demonstrated to several people. A frequent comment was that the type of interaction it allowed would be most appropriate for intimate relationships. In HandJive, a user-centered, iterative design process was used to develop a handheld device for playful dyad interactions, which rotated along two perpendicular axes (Fogg et al., 1998). This process uncovered a tendency for users to 'fight' each other, suggesting a need for a design approach that counteracted this behavior. Both InTouch and HandJive were direct interactions, i.e. neither had a mediating virtual model.

More recent projects have concentrated on designing and prototyping new devices for mediated person-to-person touch interaction. In LumiTouch, a picture frame interface used touches to send and light to display messages (Chang et al., 2001); similarly, a touch-sensitive scarf used embedded buzzer displays (Bonnanni et al., 2006). Other projects have used the metaphor of a hug as inspiration for device design (DiSalvo et al., 2003; Mueller et al., 2005). Haans provides an excellent recent survey, and observes that "the field has been lagging behind in developing a deeper theoretical understanding of the presumed effects of mediated social touch on the social interaction process. Such an understanding could potentially provide structure to the design space of social touch systems …" (Haans and IJsselsteijn, 2006).

Haptics has also been used more generally in interpersonal activities. Two studies considered the effect of a haptic component on a sense of presence in a virtual environment (Basdogan et al., 2000; Sallnas et al., 2000), and another the effect of a vibrotactile haptic interaction during an audio conversation (Chang et al., 2002). In conditions without prohibitions on audio use, use of the haptic signal often mirrored nonverbal signals in co-located communication, e.g. for emphasis and desire to speak. A study specifically exploring the use of haptics to mediate turn-taking found that the haptic signal was utilized and appreciated by remote collaborators using a shared application to do a task; further, results suggested that use of the haptic channel positively influenced equitability of turn-taking and sharing of control (Chan, 2004; Chan et al., 2005).

In her seminal paper on affective computing, Picard identifies better support of mediated person-to-person affect communication as a key application (Picard, 1995). There has been little effort to do this with haptics, but the idea is explored elsewhere. In virtual environments, different predefined affective gestures (Fabri et al., 1999) and facial expressions (Fabri et al., 2002) have been defined. An observational study of users in a virtual environment using predefined affective gestures found that participants made use of what was available rather than looking for other gestures, though several suggested that virtual touch interactions would also be useful.

Another evaluative approach is based on *un*mediated and non-realtime visual communication: ''viewer'' participants watch emotionally evocative slides while being videotaped, then talk about the experience and their emotional state. Later, other participants view the videos of the viewers, and determine which slide was shown and the viewer's emotional state (Wagner et al., 1993). This approach was designed to study human ability to send and recognize spontaneous emotion, and is similar to human in that both the sender and receiver participate. Unlike our approach, the interaction is not immediate or interactive, and involves a felt emotional response.

3. Approach

We have taken a structured approach to addressing a new design problem, beginning with a high-level consideration of the larger design space and an analysis of likely dimensions. Then we use a systematic prototype-evaluation cycle to validate both hypotheses of dimension importance, and instantiations of these dimensions. We discuss each of these below.

3.1. Design space

The design space for haptic interactions that support mediated person-to-person communication of affect is immense. It has three major subspaces: the *type of human interaction* that is being mediated, the *haptic device* and the *virtual mediating model.* In this paper, we are principally concerned with exploring the role of a mediating model, but briefly consider all three variables here.

The different types of human interactions that could occur through a mediated haptic channel can be described by variables that include the number of people involved, interaction synchronicity, and direction (can all parties send *and* receive, or do some only receive?). We have focused on synchronous, bidirectional dyadic interactions. Thus the models we consider take as input two motion signals (the actions of the two users on two haptic devices) and output two different haptic signals (the output to two haptic devices, which is felt by the users).

The mechanical and aesthetic forms of the physical device used to facilitate the communication can vary dramatically. Capabilities of a specific display (ranging from buzzer to complex robot) and its aesthetics are clearly critical to the details of model implementation, and will likely impact a user's affect response. However, because our primary interest is in the dynamic interactive model, we used a relatively neutral-affect and minimally capable (in terms of degrees of freedom) device so as to isolate the effect of these factors.

Given a specific device, the computer that mediates the communication can be programmed to arbitrarily map user actions to device output. The primary goal of the work described here is to initiate a structured exploration of the affect dynamics of this mapping model. This subspace can again be divided into three areas, as follows:

1. Literal reproductions of co-present touch communication.
2. Models created using co-present touch as metaphorical inspiration.
3. Completely new physical interaction paradigms.

While literal reproductions of natural touch are an interesting technical challenge, we are most interested in design possibilities for new interactions. Co-located experience can nonetheless inspire mediated interaction models, by giving both designers and users a grounded point of departure as well as expressive leverage on the rich meanings in co-located touch. Thus, co-present interactions inspired our investigation of the following potentially influential dimensions.

Metaphors and intimacy: There are many ways in which people interact physically in co-located settings. Some involve direct touch (hugging, patting, shaking hands, dancing); we can also interact physically but indirectly (by kicking a ball, playing tennis, carrying a table or playing tug-of-war). Descriptors of this diversity include degree of reciprocity, typical duration and context. One way communication researchers have approached direct touch is to look at the intimacy of different touches (Nguyen et al., 1975). We extended this idea to the whole physical interaction space and implemented several interactions at different points along this intimacy dimension.

Modeling personal space: When co-present, people use interpersonal distance in their nonverbal language to indicate (for example) interaction intimacy and emotional orientation (Knapp and Hall, 2002). We theorized that in a virtual space designed as a metaphor of co-present interaction, it would be possible and useful to indicate virtual interpersonal space; we developed model variants to investigate this.

Relationship: In the social sciences and communication literature, it is recognized that the relationship between individuals helps define a communication event (Heslin and Alper, 1983; Hartley, 1993); in particular, relationship and gender influence touch protocols and the meanings associated with a touch. Anecdotal reports suggest that the same may be true of computer-mediated touch; for example, responses to the intimacy of InTouch mentioned above (Brave and Dahley, 1997). Thus we have chosen here to explore the effect of relationship on haptic interaction experience.

3.2. Methodology: comparative measures of haptic affect communication

At this early stage, our primary objective is to understand the design space rather than refine usability. In particular, we want to observe how manipulations of design space dimensions impact a setup's ability to support affect communication; for this, comparative measures are most immediately useful when reliable absolute measures are unavailable or hard to interpret. To our knowledge there has been no prior effort to measure affect communication over a haptic link, so we developed a methodology for doing so.

Measuring and comparing affect communication requires several things: clarity as to the role of active modalities in the communication; an experiment task which gets subjects to demonstrate and identify emotion; and adequate performance indicators as well as supplementary data to aid interpretation. These requirements guided our methodology design decisions, which we summarize below along with issues relating to validity.

3.2.1. Methodology design decisions

In general, our challenge is to find viable compromises between technical feasibility and protocol realism and consequent generalizability. Perhaps the most critical is the practical need to employ a laboratory setting with a single brief exposure, with some predictive value as to how these interactions would be perceived and used in real contexts.

Design of experiment task: We asked dyads to convey/identify specific emotions to one another using a haptic link, which displays a coupled virtual physical model reflecting the manipulated dimensions of the haptic affect design space. For realism, we chose an interactive and bidirectional task, rather than (for example) replaying a recorded version of "happy" to see if subjects would agree. The models we used were dynamic (first- or second-order physical simulations rather than static textures) for richness and metaphor expressiveness. Finally, we assigned subjects a task of *communicating* through the haptic channel, making the exploration goal-oriented rather than free form.

Palette of target emotions: For experiment controllability, we asked subjects to convey/identify emotion words from a restricted list. To guarantee a diverse sample, we chose emotions distributed across Russell and Weiss's *affect grid* (1989), which consists of orthogonal dimensions of valence (pleasure/displeasure) and arousal.

Touch alone: For our experiment trials, we restricted communication to the haptic modality alone, in order to (a) see what *could* be conveyed by haptics in isolation; and (b) minimize ambiguity about channel role in a multimodal context. We found in pilots that subjects required a graphical rendering of the virtual model to understand it initially, but then were able to perform the communication task without it.

Data triangulation: Two keys to early design evaluation are rich data offering both objective and subjective views, and a broad shallow design surveying multiple factors and their interactions. The former is particularly useful when experiment manipulations are necessarily confounded. For example, it was difficult to separate interaction metaphor from interaction intimacy at design time, so our questionnaires included subjective questions to help interpret the influence of these factors.

Coordination between subjects: We chose not to permit subjects to discuss a communication strategy before performing the task, and they had no external feedback or other mechanism by which to coordinate their use of the interaction models. In actual use, dyads would have context to help them interpret and learn a language, and could verify and coordinate through other channels as they developed their language. However, such coordination would diminish our ability to assess the intuitiveness of our metaphors and their implementation, instead allowing subjects to learn and use a (not necessarily natural) code.

4. Study description

Through exploration of the design space we decided that *interaction metaphor*, *indication of interpersonal space* and *relationship* were the three best dimensions to examine more closely for their ability to help support affect communication in mediated haptic interactions between dyads. To do this, we developed a set of metaphor-based interaction models, and designed an experiment following the general methodology described above.

Our primary goals were to determine whether our chosen factors influenced a given virtual model's support of emotional communication, alone or in combination, in terms of either objective performance at communicating specific emotions or self-reported experiences. To this end, dyads were asked to convey/identify specific emotions using a haptic link, which displayed a coupled virtual physical model reflecting the condition's metaphor and personal–space indicator.

4.1. Factors and design

Two of our experimental factors related to interaction model and one to the participants (Table 1). In a mixed experimental design, each dyad used all four metaphor and

Table 1
Experiment factors

Factor	Levels	Type
Interaction model metaphor	PingPong/HandStroke	Within subjects
Haptic indicator of interpersonal space	Present/Absent	Within subjects
Relationship of pairs	Strangers/Couples	Between subjects

personal–space indicator combinations; relationship was tested between-subjects. The four within-subjects conditions were arranged using a balanced Latin Square to limit order effects, and repeated 20 times within these blocks for a total of 80 trials per dyad.

4.1.1. *Metaphor*

We created several interactions based on metaphors with different levels of intimacy. Experiment size restricted testing to two, for which we chose a game interaction and an intimate direct touch interaction (Figs. 1 and 2).

Low intimacy: *PingPong*. The PingPong metaphor is of two people playing a game with a ball and two paddles. The haptic knobs represent the paddles; the motion of a virtual ball moving between them determines the force on the paddles. Each person controls the horizontal motion of a Ping Pong paddle: hitting the ball speeds it up while cradling it slows it down. A virtual net (not shown) separates the two players. Running into the net generates a strong sharp force, like hitting a wall.

High intimacy: *HandStroke*. Stroking is one of the most intimate forms of co-present touch (e.g. Nguyen et al.,

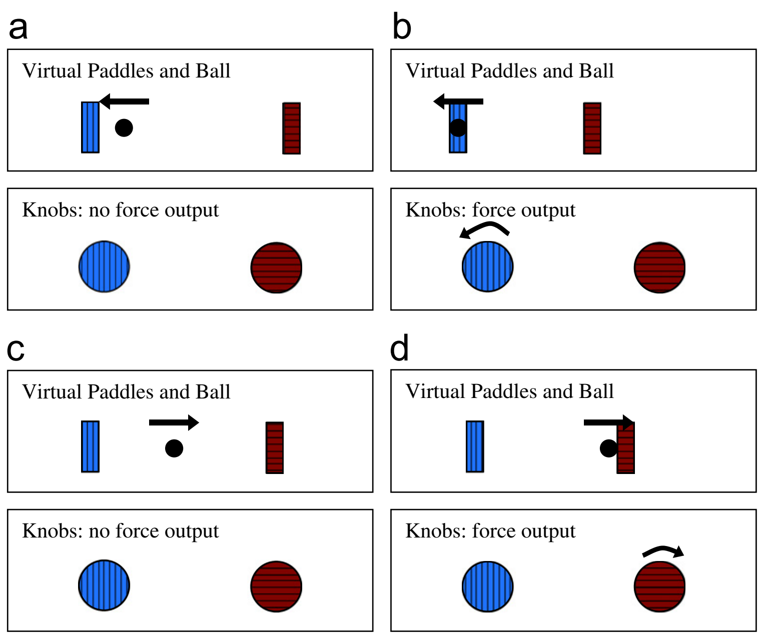

Fig. 1. A sequence using the PingPong interaction: (a) no force is felt when the ball is in the middle. (b) As the ball hits the left (green) paddle and changes direction, a counterclockwise force is felt on the left user's knob.

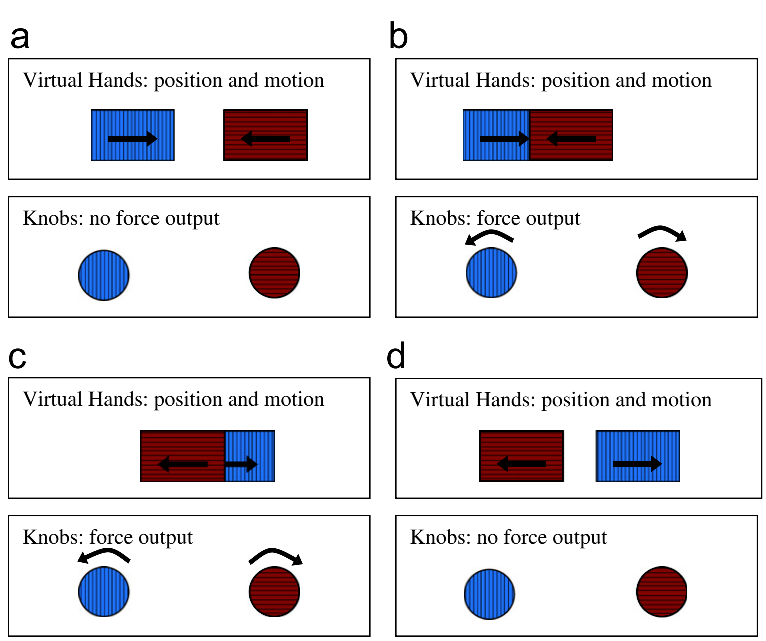

Fig. 2. An interaction sequence with the HandStroke metaphor interaction: (a) the hands are moving towards each other but not touching so no force is felt. (b) As the hands move across each other a force depending on the relative velocity is felt.

1975); the HandStroke interaction implements it as two hands pressed palm to palm and moving across each other. When the virtual hands are in contact, relative motion feels like sliding across a surface, with friction determined by relative velocity and overlapping area of the virtual hands. Metaphorically, slow movements suggest the two hands being pressing against each other, while fast movements are like a quick, light brush.

4.1.2. Indication of interpersonal space

We hypothesized that the presence or absence of a haptic display of a partner's relative position (manifested, e.g. as rushing or crowding versus respectfully standing back; playful or intimate closeness versus a formal or even cold distancing) in the virtual physical space would influence communication performance and/or the user's experience. We developed several candidates and ran two pilot studies to choose the best.

All candidates were continuously displayed vibrotactile sine waves whose amplitude and/or frequency depended variously on the distance between the two users in the virtual space. We used haptic vibrations rather than lower-frequency, grounded forces to integrate with the metaphor-based interaction models (which utilized force feedback) without confusing the meaning of the forces. The best pilot performer was a 20 Hz sine wave whose amplitude *increased* linearly as the virtual distance between users *decreased*; when using it, subjects chose the correct distance bin (near, midway or far) to a simulated "other" 80% of the time.

4.1.3. Relationship

We varied relationship intimacy by recruiting dyads who were either couples (romantic partners of at least 6 months) or strangers. In all cases, the pairs were cross-gender—one male, one female—to avoid confounds of relationship with gender pairing.

4.2. Setup

During the experiment the two subjects were located in the same room, but were unable to see each other or interact physically or verbally (Fig. 3). Each subject had a personal haptic display but was able to see the same LCD monitor, which was used to display a graphical version of the metaphors during condition training. During the experiment trials, the LCD provided procedural but no metaphor or model information. Strangers did not meet, speak to or see one another prior to the experiment.

The haptic displays were an identical pair of single-degree-of-freedom force-feedback devices (Fig. 4). Impedance-controlled DC motors (Maxon RE025) supplied the computed virtual model with current position from 4000-count/revolution (post-quadrature) optical encoders, which in turn commanded their torque. Each motor was configured in direct drive with a circular polycarbonate handle (64 mm in diameter) connected to its output shaft.

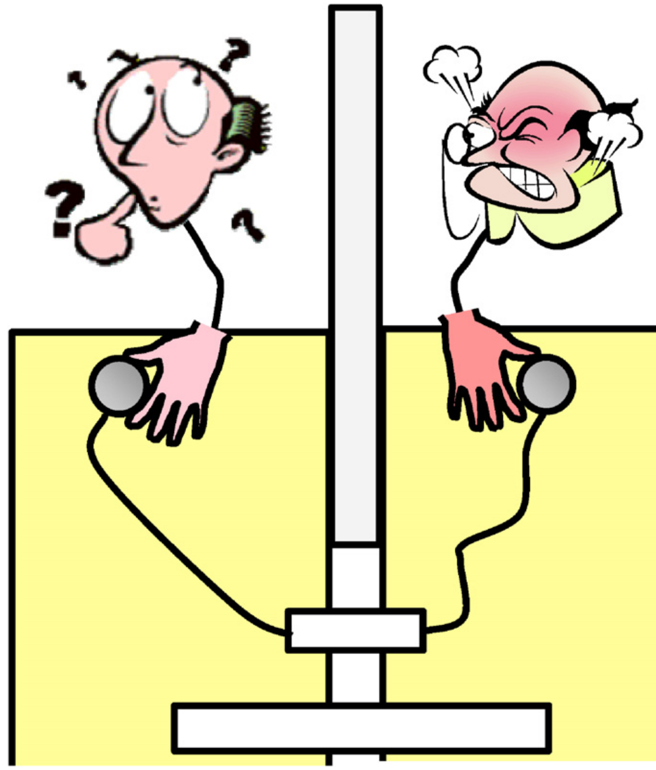

Fig. 3. The participants sat on either side of a dividing wall and communicated only through the haptic device.

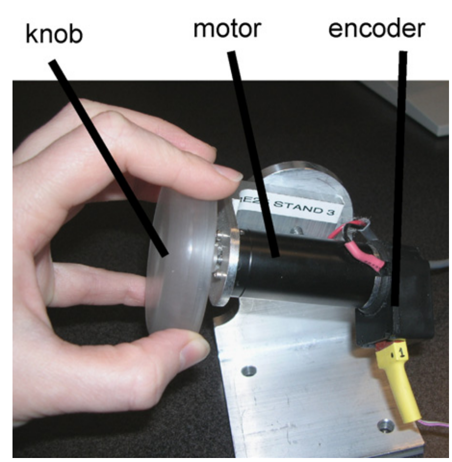

Fig. 4. A simple 1-degree of freedom haptic knob was used as the haptic communication device.

With a Pentium III 1 GHz computer running Windows XP, we achieved an average update rate of 2 kHz and stable rendering of the virtual models used.

4.3. Experiment task, protocol and response variables

Task: In a given trial, one member of a dyad was asked to communicate an emotion, assigned from one of four possibilities, using only the haptic knob which was running one of the four within-subject condition sets. The target emotion was listed on a sheet of paper given to the conveyer. The other member was asked to choose which of the four possibilities had just been conveyed by selecting the appropriately labeled key from a keyboard. The shared graphical display indicated when a new trial had begun, and nothing else during the experiment trials.

Emotion words: We chose four emotion words (Angry, Delighted, Relaxed and Unhappy) for their ability to distinctly represent the quadrants of the affect grid. Randomly ordered lists of 20 emotion words (5 repetitions of each emotion) were divided in half; one dyad member conveyed the first and the other the second half. A different emotion ordering was used for each condition. The emotion lists themselves were used in the same order for every pair, while within-subject condition order varied according to a balanced Latin Square design.

Protocol and objective measure: For each condition (executed in a block of 20 trials), the condition was described using scripted instructions, then the subjects were trained simultaneously with access to a graphical rendering of the current interaction (shown on the shared display for training only) until both indicated they were comfortable with and understood it. Next, each individual conveyed a list of 5 emotions with the graphics rendering on. In both phases, subjects were told that during the experiment there would be no graphical rendering, and were encouraged to close their eyes during training. The entire training for the condition lasted between 10 and 15 min. The 20 experiment trials for that block were then carried out with a maximum of 16 s for each emotion identification task.

We employed one objective performance measure: the number of trials in which pair successfully communicated emotion in each condition.

Questionnaire: At the end of the experiment, each subject answered a post-study semi-structured questionnaire designed to elicit both quantitative and anecdotal responses regarding subjective experience with each of the interactions and communication strategies. Five questions solicited overall choices for preference, connection, comfort, ease of conveying emotion and ease of perceiving emotion. Within each interaction model (representing a combination of metaphor and space indicator conditions), participants were asked to comment on what made it enjoyable and easier to convey/perceive emotion, and what they would change. With regard to strategy, we asked whether they moved while receiving, found themselves expressing the same emotion as they believed the conveyor was expressing, and whether they modified their strategy to be more like the one they believed their partner was using.

5. Results

In this section, we summarize key experiment results. A more complete report can be found in Smith (2005).

A total of 32 individuals (16 cross-gender pairs, of which half were couples) were recruited for this study, using an online subject recruitment system and posters posted on the university campus. Participants had varying occupations with most being university students, and ranged in age from 17 to 49 (mean 24). Experiment sessions typically lasted about 2 h.

5.1. Overall performance

Participants successfully communicated emotion in 54% of trials (where chance performance would be 25%). Thus while participants were not universally successful in communicating emotion with high accuracy, they *were* able to successfully communicate much of the time.

A detailed view showing confusion patterns can be seen in Table 2, where perfect performance would appear as 100% values on the diagonal and 0's everywhere else. Each emotion was successfully identified far more often than it was incorrectly identified as any other one emotion. Angry was correctly identified most often, and Unhappy least often. These results correspond with participant comments at the end of the experiment: several observed that Angry was the easiest and Unhappy the most difficult to communicate. An apparent confusion between Unhappy and Relaxed also corresponds to participants reports; during post-study discussion several pairs discovered that they were using opposite strategies for Unhappy and Relaxed.

When an emotion was misidentified, it was usually mislabeled as the emotion with the same arousal or valence. Overall the perceived emotion had the same arousal and/or valence in 90% of the trials (chance = 75%).

Table 2
This table shows the percentage of trials that the row emotion was received when the column emotion was conveyed

Perceived emotion	Sent emotion (%)			
	Angry	Delighted	Relaxed	Unhappy
Angry	62.2	9.4	2.5	6.2
Delighted	23.1	49.2	14.7	15.3
Relaxed	6.6	24.8	56.9	30.8
Unhappy	8.4	16.3	25.9	47.6

The correct responses lie along the diagonal.

5.2. Factor analysis

5.2.1. Metaphor and personal space indicator

The experiment was designed to enable performance comparisons of different haptic interactions created by varying metaphor/intimacy and the presence/absence of a personal space indicator. We found a significant effect of metaphor (Table 3); specifically, emotion words were successfully communicated in 11% more trials with HandStroke than with PingPong ($p = 0.04$).

No significant difference in performance was found for the space indicator we used, but there was an interaction effect between metaphor and space indicator ($p < 0.01$): adding the indicator to PingPong improved performance by 9.0%, but adding it to HandStroke *lowered* performance by 7.5% (Fig. 5).

Subjectively, the majority of participants (84%) reported feeling more connected with the HandStroke interaction ($\chi^2 = 15$, $p < 0.01$). As well, participants reported preferring, feeling more comfortable and more connected with an indicator of personal space present (81%, 78% and 81%, respectively) for the metaphor they selected for each of these attributes. All these results were statistically significant ($\chi^2 = 34$, 30, 34 and $p < 0.01$).

Finally, we asked each participant to choose the metaphor through which they found it easiest to convey and perceive emotion, and then to indicate whether they further found it easiest it with personal space indicator. In total, 24/32 subjects indicated HandStroke and 18 of these 24 indicated it was easiest with personal space indicator. Of the 8/32 participants that indicated it was easiest to communicate with the PingPong metaphor, 7 found it easiest with the personal space indicator.

Table 3
The successful communication of emotion results according to metaphor

Metaphor	Mean # correct (40 trials) ± SE	Mean percent correct ± SE
PingPong	19.5 ± 1.4	48.3 ± 3.5
HandStroke	23.8 ± 2.1	59.5 ± 5.3

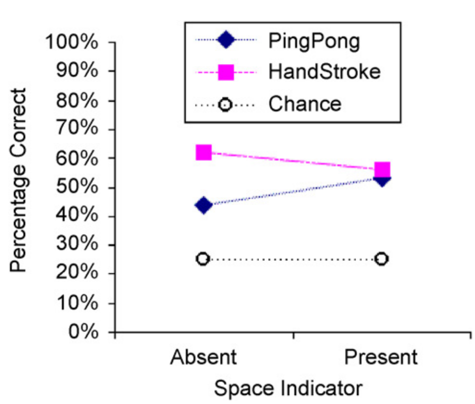

Fig. 5. Interaction effect on communication performance between metaphor and space indicator (chance performance is 25%).

5.2.2. Relationship

Half the pairs in our study were strangers to each other and half were couples. We hypothesized that the type of relationship the pair shares would affect their ability to communicate emotion; specifically, that couples would be more successful at communicating emotion than strangers. Couples did appear to be more successful at communicating emotion, at $60.0 \pm 6.5\%$ correct over 80 trials vs. $48.3 \pm 3\%$ for strangers, a performance difference of 11%; however, this result is not statistically significant ($p = 0.12$).

We found statistically significant interactions between relationship and metaphor for the subjective metrics of metaphor preference and comfort. Specifically, the majority of individuals in stranger pairs reported preferring and feeling more comfortable with PingPong, whereas the majority of individuals in the couple pairs reported preferring and feeling more comfortable with HandStroke (Fig. 6 and Table 4). Several participants who were part of stranger pairs explicitly expressed feeling discomfort with the HandStroke interaction.

Some couples had very high performance rates. Five out of eight couples communicated successfully in at least 90% of trials in at least one of the HandStroke metaphor conditions, whereas no stranger pairs approached this performance level.

5.3. Self-reports and observations

Many participants reported that their interaction was dynamic, changing during the session. A total of 63% indicated that they would sometimes mirror the emotion that they thought was being conveyed, while 72% indicated

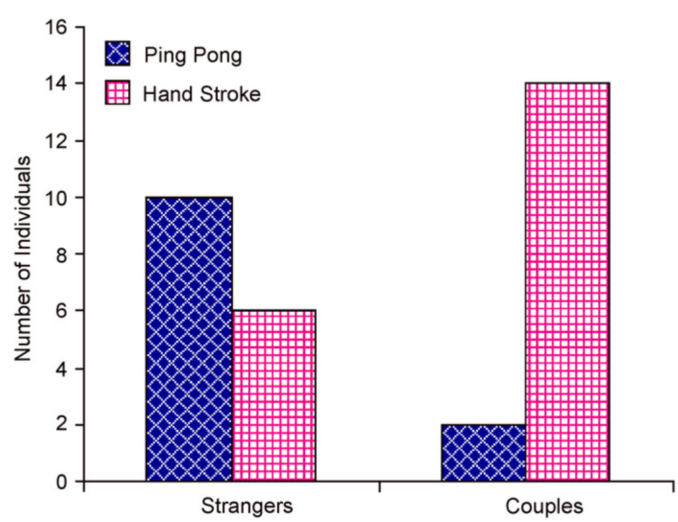

Fig. 6. Comfort with metaphor, by relationship (number of individuals expressing comfort, out of 16 individuals).

Table 4
The association between relationship type and preferred/more comfortable metaphor is statistically significant, according to the χ^2-test

Association between relationship and	χ^2	ϕ	p
Preference	6.35	0.445	<0.01
Comfort	8.50	0.516	<0.01

ϕ is a measure of the strength of this association.

that they changed their strategy to be closer to the strategy that they thought their partner was using.

Some participants offered comments about whether this kind of mediated touch interaction would be appropriate for communicating emotion. Specifically, one participant did not think that this type of interaction would be a very easy way to communicate emotion since "touch isn't something you do that often." When asked if the task was difficult, another participant indicated that he did not find it difficult but that it was not interesting to him. Others were more positive, with comments like "I enjoyed this very much." One participant was particularly enthusiastic about this kind of interaction: "HandStroke with Indicator was a perfect way of communicating problem/feelings without actually talking or looking at one another. Seems like a great new form of communication when one person is feeling things they can't express in words."

6. Discussion

Our goal in this paper has been to explore the idea of computer-mediated haptic interaction as a channel for remote communication of affect. Our study has focused on an important part of the design space of virtual models that could mediate interpersonal haptic communication. We carefully chose several points in the space and made objective and subjective comparisons of subjects' ability to use them to communicate affect. In this section, we start by reviewing our starting assumptions about haptic value in this context. We then look at the design space experiment results, and finally consider the evaluation methodology itself.

6.1. *Value of the haptic modality for affect communication*

Underlying this work is an assumption that haptically displayed interaction models can support remote emotional communication. This hypothesis of a basic *value proposition* for a haptic role in emotional communication is derived from the importance and diversity of meanings that the social sciences have found to be associated with interpersonal touch, as well as the reactions we and others have observed informally when people use haptic displays programmed in other contexts. Although our experimental approach focuses on relative comparisons of design space manipulations rather than measuring absolute communication value, we also care about how well the communication we have observed predicts performance in a real context. Here we consider this technique's power to offer such insights, and review the data with this in mind.

6.1.1. *Methodology limitations*

Construct validity: *Simulation of emotion*. In a laboratory setting, it is difficult to reliably induce felt emotion so instead we asked subjects to convey specific emotions from a list of emotion words. Thus the communication strategies they used to convey the various emotions are a cognitive approximation of the actual communication strategies that would be used with felt emotion. Thus, a potential threat to the construct validity of our approach is that we do not know how closely these cognitive strategies approximate felt strategies. However, Collier suggests that simulated emotions are a good starting point for examining emotional communication (Collier, 1985). Further, if unfelt emotion *can* be communicated successfully, it seems probable that felt emotion could also be expressed through this channel—though the communication strategies could possibly be different.

External validity: *Realism of experiment task and context*. A realistic task lends confidence that the observed communication would also occur in a real-world setting. The task we ask participants to perform (i.e., to convey/identify a specified emotion word from a short list of possible words) is both more difficult and simpler than the actual communication of affect through haptics in a real world setting. It is more difficult in that subjects are not permitted to coordinate their strategies, and because the whole concept of synthetic haptic feedback and the specific interactions are unfamiliar. On the other hand, the experiment task is probably *easier* because it is limited to a small number of distinct emotions, reducing the number of choices and the opportunity for nuance. Overall, we would expect that the ability to use context to learn a partner's strategies and modify use of the interaction as a pair would lead to better performance in real-world interactions over time, even for more complex and less distinct emotions. Thus, we hope that this protocol design is, on balance, conservative in terms of modeling real task difficulty. Other aspects of task realism, such as emotion complexity, will be usage-dependent. Successful performance here does not prove success for more complex tasks, but is a necessary first step.

6.1.2. *Experimental evidence*

With these limitations in mind, we proceed to examine the evidence that subjects were able to communicate emotion via this haptic link and its physical metaphor models.

Identification performance: Objective results suggest that considerable emotional information can be communicated, with potential for more. The overall average was more than double that of chance response. In almost all trials either arousal or valence was correctly communicated, and each emotion is identified correctly more often than it is confused with any one of the others. Furthermore, a majority of participants reported adapting their strategy to reflect the one they felt their partner was using. This adaptation was not necessarily successful, but suggested empathy: with more context or coordination this tendency would likely improve performance and engagement. Finally, the particularly high success rate of a majority of couples at communicating emotion with HandStroke suggests that some people can find and use a language for communicating cognitive emotion with our interaction models, even without feedback or context.

Achievement of emotional connection: Subjective evidence of an emotional connection or reaction (or lack thereof) developed during the course of the experiment would help clarify the capacity of this channel to communicate true (felt) affect. We found both to some degree. On one hand, the amount of emotional information successfully communicated in our experimental context was significant but limited in scope, and some participants observed that the task was difficult. Conversely, a number of couples enjoyed the feeling of connection they felt with each other while using the interactions, and volunteered that it seemed a natural channel for emotional nonverbal communication. Perhaps most compellingly, some individuals in stranger pairs indicated social discomfort—particularly with the intimate HandStroke.

Overall these observations suggest that to be appropriate for emotional communication, mediated haptics will require learning and coordination. However, significant positive performance results and connections in this first-pass attempt certainly support the premise that the haptic channel *can* afford remote communication of affect.

6.2. Examination of design space parameters

We set out to explore an important design subspace of computer-mediated haptic interactions, and its effect on performance and subjective experience. Here we discuss the implications of our results for others working on this problem.

6.2.1. Metaphor

We based the haptic mappings used in our study on two metaphors chosen to represent different levels of intimacy: the game-like PingPong and the highly personal HandStroke. Objective performance was best for HandStroke, and while subjective reports were overall in favor of HandStroke, they also depended on relationship. Neither relationship nor its interaction with metaphor, however, had a statistical effect on objective performance.

We cannot definitively say whether the primary influence on these results was in fact due to the intimacy of the metaphor, or to other implementation aspects that varied between the two models. However, self-reports indicate that a variation in intimacy was indeed perceived between the metaphors. Further, HandStroke was *overall* most preferred and created the greatest sense of connection; but while couples preferred and were more comfortable with HandStroke, strangers preferred and were more comfortable with PingPong, an observation predicted by the assumption that strangers will prefer a less intimate connection. Thus, interpreting the perceived difference between the metaphors and hence the observed performance increase as being at least in part related to increased intimacy is consistent with the combined observations.

These results confirm that when considering intimacy of interaction metaphors, the appropriateness of the metaphor for the pair's relationship is an important factor in acceptance and usefulness, since communicating pairs will probably not welcome a format that is socially uncomfortable.

6.2.2. Indication of personal space

The additional haptic vibration indicating virtual interpersonal space did not make an overall difference in performance, but it improved PingPong's performance while decreasing HandStroke's. Three possibilities exist. An awareness of personal space might be irrelevant to emotion communication in this context; but since in specific situations it *was* helpful, this is unlikely. Second, this personal-space signal might have been insufficiently clear. Third, the metaphor implementation may have been critical: perhaps dyads made use of it when the information was not otherwise available, but were overwhelmed when it was redundant (below).

Subjectively, a large majority liked the spatial indicator with their favorite metaphor. In conflict with actual performance, they also said the indicator made communication easier. This could be good or bad—over-optimistic performance perception may initially be positive, but might lead to miscommunications. In summary, the consistent perception that communication is easier with the personal space indicator is encouraging, suggesting at least a perceived causal relationship between personal space awareness and performance. Therefore, the most promising next step is to improve signal intuitiveness, thus addressing the second and third theories above.

6.2.3. Relationship

The relationship shared by dyads affects the interaction. Performance was not statistically affected, but preference and comfort put strangers with PingPong and couples with HandStroke; while observations and comments indicate outright discomfort when metaphor intimacy is not appropriate, and a more compelling (actual sense of touching) experience when it is. As in real-world interactions (Heslin and Alper, 1983), it thus appears that appropriateness of metaphor intimacy is important for comfort and salience of the experience.

6.2.4. Towards optimizing expressive capacity of interaction models

Adding the personal space indicator to PingPong supplied unique information (travel time was confounded with strike force) and improved performance: subjects reported that without it, it was difficult to differentiate the emotions. In HandStroke, however, the duration of separation served as a proxy for distance measure; the space indicator thus added only granularity and redundancy, increasing expressiveness beyond that required. It actually decreased performance, perhaps by overwhelming the user. One participant commented that with the space indicator, she needed to think rather than feel.

Thus, results suggest that matching an interaction's expressive capacity to task difficulty leads to better performance. This leaves open the question of how well this particular "rich" feature would support a more complex emotion communication task. A clue is present in the preference and (false) increased ease of communication with the space indicator for HandStroke: people may prefer greater expressiveness even when unsure how to use it.

6.3. Assessing the evaluative methodology

The experimental approach of asking pairs to communicate emotion words via a haptic link produced a quantitative comparison of the degree to which different haptic interactions facilitate communication of emotion words. Through this comparison, we were able to establish a performance difference between interaction metaphors. Combined with the design rationale developed above, our results offer some design insights.

Data triangulation: The combination of objective metrics and subjective responses for data triangulation was invaluable for interpreting results. It revealed that comfort and preference are as important design-wise as performance (and indeed may affect it). Along with the factor interactions, the practice also helped to unravel the unavoidable metaphor-intimacy confound.

Use of single modality: We conducted our experiments using the haptic modality alone, for unambiguous attribution of any successful communication observed to the haptic setup rather than unintended multimodal interactions. We did find both objective and subjective indications of emotion communication and connection using a solely haptic link.

Subject motivation: In an emotions communication task, couples may have a vested interest in being able to communicate emotionally that strangers do not share. Further, being able to successfully use such a new interaction could be seen as an indication of a strong connection for a couple. This is a factor that should be considered in design of future studies.

External validity and appropriate application of methodology: Known threats to this experimental methodology's external validity included a task that involved conveyance of simulated rather than felt emotion, variation of task difficulty from real-world situations, and artificiality of the laboratory setting. The first two were considered in 6.1, and the third is clearly related to them. Overall, these concerns are real but do not appear to undermine the meaningfulness of the early results obtained with this laboratory-based comparative evaluation. Internal data consistency and positive effects indicate that the methodology is a practical first step towards systematically exploring a haptic affect-communication design space. Increasing external validity would greatly increase experiment cost before the promise of the design approach is established, but will be needed at later stages. Meanwhile, the use of the device in a lab environment may suggest how such a device *would* be used outside the lab, over longer periods of time.

7. Conclusions

We have proposed the initial outlines of a design space relating to remote haptic communication of affect, and analyzed and prototyped within a subspace encompassing the virtual interaction model and key user attributes. To assess the importance of what we felt were key dimensions of this space, we developed a methodology to measure the influence of design parameters on objective and subjective indicators of affect communication success. Our larger goal was to systematically obtain a sense of what matters to users, and in the process, we succeeded in demonstrating that affect *can* be communicated over a purely haptic link. Moreover, our methodology is a first instance of evaluation in this area, and we have shown it to be both practical and informative for this kind of exploratory investigation.

Our results are promising, but much remains to be learned. Practical next steps are to refine the parameters studied here, e.g. the promising but hard-to-read personal space indicator, and to investigate other dimensions. More basic questions also arise: for example, there is reason to believe that touch and vision have qualitatively different contributions to an affect experience, and a multimodal study similar to this one could shed light on this. Longer term, we will need to find more realistic test tasks, and in particular mechanisms to evaluate felt rather than simulated emotions.

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