Emotional and Behavioral Responses to Haptic Stimulation

Conference Paper · January 2008

DOI: 10.1145/1357054.1357298 · Source: DBLP

Emotional and Behavioral Responses to Haptic Stimulation

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ABSTRACT

A prototype of friction-based horizontally rotating fingertip stimulator was used to investigate emotional experiences and behavioral responses to haptic stimulation. The rotation style of 12 different stimuli was varied by burst length (i.e., 20, 50, 100 ms), continuity (i.e., continuous and discontinuous), and direction (e.g., forward and backward). Using these stimuli 528 stimulus pairs were presented to 12 subjects who were to distinguish if stimuli in each pair were the same or different. Then they rated the stimuli using four scales measuring the pleasantness, arousal, approachability, and dominance qualities of the 12 stimuli. The results showed that continuous forward-backward rotating stimuli were rated as significantly more unpleasant, arousing, avoidable, and dominating than other types of stimulations (e.g., discontinuous forward rotation). The reaction times to these stimuli were significantly faster than reaction times to discontinuous forward and backward rotating stimuli. The results clearly suggest that even simple haptic stimulation can carry emotional information. The results can be utilized when making use of haptics in human-technology interaction.

Author Keywords

Haptics, emotions, tactile communication, affective space, human-technology interaction, sense of touch

ACM Classification Keywords

H5.2 Information interfaces and presentation: User Interfaces – Haptic I/O

INTRODUCTION

Using the sense of touch in human-human communication and interaction clearly has several functions. These functions extend from cognitive functions such as getting ones attention to emotional functions like caressing ones faces. There is no doubt that the use of sense of touch has profound importance in human communication and interaction [e.g., 19]. In this perspective it is understandable that the idea of adding tactile qualities to different computer applications has attracted interest of several research groups and companies worldwide [18,21,23,28]. The field that studies the use of the sense of touch and its applications in human-technology interaction is defined as haptics.

Although one significant function of sense of touch in human-human interaction is related to human emotion systems, most of the current research in human-technology interaction has so far concentrated on the cognitive side of affairs. By this we mean that haptic information is mainly used for alerting or informing purposes. The most commonly used haptic feedback types are vibration and force feedback. However, haptics covers a wider spectrum of means to create tactile sensations such as friction and skin stretch [16,35,37].

In review of the previous work it seems that quite many studies on haptics have focused on how easily different haptic stimuli can be grouped or otherwise identified from each other. MacLean and Enriquez [22] tested how different haptic icons presented with a haptic knob would be sorted in groups using any criteria the participants chose. The icons they used were varied by waveform (sine, square, sawtooth), frequency (Hz) and amplitude (newton-millimeters). They found out that frequency information of the stimulus was the basis of the classification for most participants.

The tactile channel has also been utilized to convey abstract information in the means of haptic communication. Especially vibrotactile feedback has been used in these experiments because it is fairly easy and inexpensive to produce. Brewster and Brown [5], Brown *et al*. [6], and

Brown and Kaaresoja [7] have all studied the use of tactons (i.e., structured, abstract messages that communicate complex contents to tactile sense). By modulating either the amplitude [5,6] or the frequency [7] of the stimuli they have defined the vibrotactile roughness that is reported to be a good dynamic parameter to distinguish different information contents of a message.

Rovers and van Essen [26,27] went one step further by studying how to use hapticons (i.e., vibrotactile icons representing smileys) to enrich instant messaging. They designed a set of six vibrotactile patterns symbolizing different smileys. However, these stimuli were based on the intuition of the authors themselves thus lacking the ecological validity of the emotional qualities of the stimuli. Another study by Smith and MacLean [32] used a prototype of a haptic turning knob to study the communication of four distinct emotions between two people (i.e., dyad). Half of the dyads were strangers and half of them were in a romantic relationship. It was found that the dyads with romantic relationship performed significantly better in identifying the haptically presented emotions as compared to the dyads of strangers.

As argued above, the cognitive side of affairs such as identification of stimuli is only one (though an important one) part of studying haptic messaging. It is known that touch and haptics are clearly related to human social and emotional communication and psychological development. Perhaps one of the most dramatic examples of the importance of touch dates back to 1950's when Harlow [13,15,33] made experiments that showed how essential touch is for social development of monkeys. Harlow studied how the lack of mutual touch affected on monkeys' early social development. He let baby monkeys have water and food, but instead of spending time with an adult monkey, they had a "mother" made out of iron and soft cloth. These monkey babies grew up to be unsocial individuals. According to Harlow [14] touch and body contact is a biological need essentially related to attachment and love with both animals and human beings.

Human studies have found, for example, that participant's heart rate decelerated significantly when the experimenter touched the participant's wrist [11]. Hertenstein *et al*. [17] found that humans could identify intended emotions conveyed by touches of a stranger. Distinct emotions of anger, fear, disgust, love, gratitude, and sympathy could be identified in the accuracy of 48–83 % which was well above chance level.

A number of prototypes have been developed for haptic emotional interaction. These devices are motivated by the idea that touch is an important channel for communication and it can, among other important functions, ease the feeling of social isolation. Users like the elderly and lovers geographically apart from their beloved ones could use these devices for intimate communication. Even though the tests done with these devices have been relatively informal, but generally speaking participants have mostly found them useful and pleasant. These devices include, for example, LumiTouch which is a photo frame that turns touch input into flashing lights [8], Hapticat which mimics reactions and purring of a cat [36], TapTap which is a blanket that provides comforting tap of vibration to the shoulder of a user [3], and The Hug, a special pillow which provides a vibrating "hug" to a loved one far apart [10].

The earlier research in haptics and emotions has been done by building a prototype technology (hardware and software) and after that designing the preplanned features for that device. Then it is believed that the built technology is capable of emotional stimulation or mediation as such, and that the product is ready. The other way of doing research is to put people to use the technology with the instruction that they are to communicate some distinct preplanned emotions to each other, and then see what happens. The latter approach represents the view that emotions are distinct categories that have a specific pattern of expression like, for example, in the face [12,29]. There is also evidence that the differentiation between spontaneous and acted emotional facial expressions do exist but special arrangements are required to find them out [34]. It is probable that like in facial expression research, also haptic stimuli and "expressions" can mediate distinct emotions but so far there is no knowledge on the physical qualities of haptic stimuli in order to systematically create such messages.

One alternative way to proceed is to start to measure emotion related responses to haptic stimulation as such. This could offer one way out in setting aside device specific questions which is very much needed also according to Smith and MacLean [32]. Emotion related reactions can be measured in multiple ways. One can measure low level reactions like pupil size variation, facial electromyography, ballistocardiography, and more high level responses like ratings of personal emotional experiences with various scales [e.g., 1,2,25]

In studying the possible emotional reactions haptics can evoke, it is reasonable to start with higher level measures. There are basically two approaches in emotion research. One can work with the differential emotions theory in which emotions are seen as distinct categories (e.g., happiness, sadness, anger, surprise) each having their specific motivational properties [e.g., 12,19,34]. Alternatively one can work with the dimensional view of emotions that maps emotions as combinations of two or more dimensions [e.g., 4]. These two different approaches can rather be seen as more complementary than contradictory to each other. As argued above, at the moment we are somewhat shorthanded in preplanning discrete emotional messages for information technology so it might be feasible to start with the dimensional frame of reference.

A three-dimensional affective space by Bradley and Lang [4; see also 24,30] has been frequently used to analyze emotion related ratings of subjective experiences to various stimulations. This affective space consists of three bipolar dimensions (i.e., scales) of valence (unpleasant–pleasant), arousal (relaxing–arousing) and dominance (feeling of being controlled–being in control). The medium of each scale represents a neutral point (e.g., neither unpleasant nor pleasant). As emotions are frequently argued to be centrally connected to the motivation of avoiding and approaching something [e.g., 9], it is important to measure this dimension as well.

The aim of this research was to study how different haptic stimuli can affect subjective ratings when measured with various affect related bipolar dimensions. We also wanted to know how fast and accurately these stimuli could be distinguished from each other. For this purpose, a prototype of fingertip friction stimulator was built. Stimuli were presented in pairs and participants had to indicate whether the stimuli were the same or different. After this participants rated all the stimuli one at a time with emotion related bipolar scales evaluating the pleasantness, arousal, dominance, and approachability of each stimulus.

METHODS

Participants

Twelve voluntary participants (3 females, 9 males) participated in the study (mean age 27 years, range 19–43 years). Two of the participants were left-handed and ten of them were right-handed by their own report. One male participant was rejected from the analysis due to technical problems during the experiment. Thus, the results are based on data from 11 participants.

Apparatus

The prototype of the fingertip friction stimulator (see Figure 1) consisted of a plastic box having a narrow rectangular hole (34 mm × 8 mm) that allowed placing one or two fingertips to sense the surface of the rotating cylinder installed inside the box. The finger force applied to the cylinder was not measured but the device had an adjustable spring-loaded construction to regulate the maximal elevation and resisting force of the cylinder. In the current prototype the rotation cylinder had a diameter of 3 mm and it was implemented as a continuous leadscrew with a pitch of 8 mm. The screw had a groove of 1 mm in width and 0.7 mm in depth with relatively sharp edges.

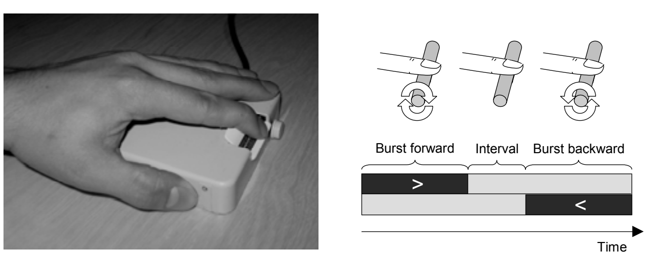

Figure 1. Picture of the prototype used in the experiment and an example of a stimulus.

Due to both the controlled fingertip pressure and torque of the driving gear, the device could be used safely when it produced different tactile sensations stimulated by skin stretch and friction force.

The PNN13GE85TD (Minebea-Matsushita Motor Corp) DC motor having an operating voltage of 1–4.5 V, rated current of 117 mA and starting torque of 0.56 mN/m (at 300 mA starting current) was used to drive the device. To transform the torque into a friction of the leadscrew with a minimal loss, the gear assembly had a reduction ratio of 12:20:15. The rotational frequency of the leadscrew was 754 rad/s.

The start-stop signal and the direction of rotation of the leadscrew was provided with dual n- and p-channel FET electronic switches (NDS9952A) and autonomic power source of two kits of 3×1.5 V (AA-type) batteries. The device was controlled directly through two digital outputs of the PC parallel port with two optocouplers (SFH615A).

The stimulus presentation was controlled and fully randomized by E-Prime® experiment generator software version 1.2 [31]. A PC recorded the reaction times and user responses. The responses were given with the Neuroscan response pad.

Experimental Tasks

The experiment was a within-subject 4 × 3 (rotation style × burst length) repeated measures design. First, two haptic stimuli were presented sequentially by the friction stimulator to the participant's index finger of the non-dominant hand. The task was to indicate whether two haptic stimuli presented were the same or different. Participants were instructed to push a button of a response pad with their dominant hand's index finger as fast as possible. This was a forced choice procedure, thus the participant had to give the answer before the next pair of stimuli appeared. The response pad had two buttons available. Red button was labeled as *different* and green as *the same*. The participant was able to respond as soon as the second stimulus began. Reaction time was calculated from the onset of the second stimulus.

Stimuli

There were a total of 12 different stimuli. All the stimuli were around 500 ms long. During that 500 ms, rotation style and burst length were varied in the following way. There were four rotation styles: discontinuous forward, discontinuous backward, discontinuous forward-backward and continuous forward-backward. Within all rotation styles, three different burst lengths were used: 100 ms, 50 ms, and 20 ms, and in the discontinuous stimuli intervals between the bursts were 33 ms, 100 ms, and 140 ms, respectively. In the continuous forward-backward stimuli there were no perceived intervals between the bursts. Figure 2 shows all the stimulus variations in detail.

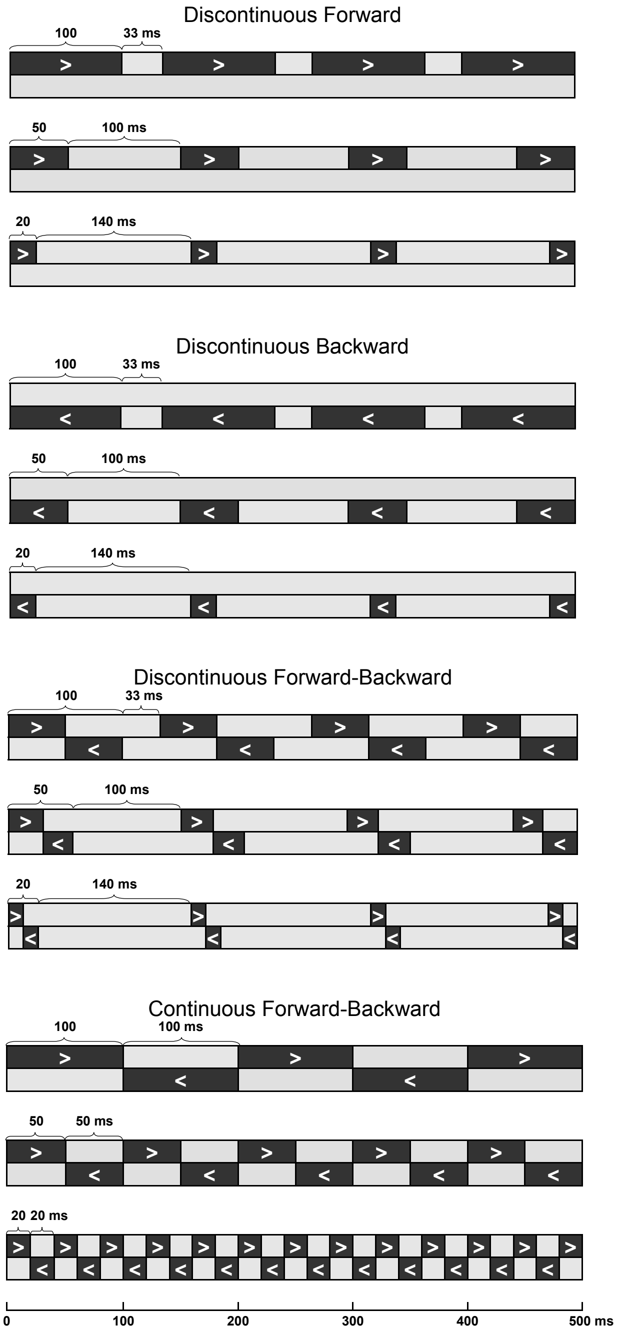

Figure 2. The burst lengths and intervals between the bursts by stimulus type. Arrows indicate the rotation direction (i.e., > for forward and < for backward rotation). Burst lengths and intervals between the bursts are indicated in milliseconds (ms).

Procedure

When the participant arrived in the laboratory, the equipment and the laboratory were introduced to her or him. The participant was told that the purpose of the experiment was to study how different haptic stimuli could be distinguished from each other. The participant sat down and put the index finger on the leadscrew of the friction stimulator, and the other hand's index finger between the buttons of the response pad. The participant was instructed to keep the gaze on the display during the experiment. In the center of the display the participant could see the order of the buttons in the response pad.

First there was a practice session of 15 trials before the experiment started. It proceeded as follows: two stimuli separated by 1000 ms inter-stimulus interval were presented at the participant's index finger. Participant's task was to decide whether the presented stimuli were the same or different. After each response, the next trial was initiated after 2000 ms inter-trial interval. The order of the response buttons was counterbalanced so that half of the participants used the right button and half of them used the left button when the answer was *the same*. In order to block the noise of the friction stimulator, the participant listened pink noise via hearing protector headset. The participant was prevented seeing the rotation of the leadscrew by covering the friction stimulator and the non-dominant hand with a box.

After finishing the practice trials the experiment began with the distinguishing tasks. All the possible combinations of the 12 different stimuli were used to form the stimulus pairs. 132 of the pairs consisted of two different stimuli and 132 pairs consisted of two same stimuli. These stimulus pairs were presented twice separated by a resting period between the blocks. Thus, a total of 528 (132 × 2 × 2) stimulus pairs were presented in randomized order to the participants.

After the distinguishing trials, the participants were asked to rate their subjective experiences evoked by the stimuli using four nine-point bipolar scales varying from -4 to +4. The stimuli were presented one at a time and repeated for each rating scale. Ratings were asked for the following scales: pleasantness (i.e., from unpleasant to pleasant), arousal (i.e., from relaxed to aroused), approachability (i.e., from avoidable to approachable), and dominance (i.e., from controlled to controlling). On each of the scales 0 represented neutral experience (e.g., neither unpleasant nor pleasant). Ratings were given using a computer keyboard with nine keys labeled from -4 to +4. Before the actual stimuli, the participant rated three practice stimuli using each scale in order to practice giving the ratings. After that, the experimenter left the room and the participant rated all the 12 different stimuli in randomized order. Conducting the whole experiment took approximately 60 minutes.

Data Analysis

Repeated measures analysis of variance (ANOVA) was used for statistical analysis. If the sphericity assumption of the data was violated, Greenhouse-Geisser corrected degrees of freedom were used to validate the F statistic. Pairwise Bonferroni corrected t-tests were used for post hoc tests. Both correct and incorrect responses were included in the reaction time analysis.

RESULTS

Subjective Ratings

Mean ratings and standard error of the means (S.E.M.) for pleasantness are presented in Figure 3. For the ratings of pleasantness, a two-way 4 × 3 (rotation style × burst length) ANOVA showed a statistically significant main effect of the rotation style $F(3, 30) = 7.4$, $p \leq 0.001$. The main effect of the burst length and the interaction of the main effects were not statistically significant. Post hoc pairwise comparisons showed that participants evaluated continuous forward-backward stimuli as significantly more unpleasant than discontinuous forward $MD = 1.9$, $p < 0.05$ and discontinuous backward $MD = 1.6$, $p < 0.05$ stimuli. The other pairwise comparisons were not statistically significant.

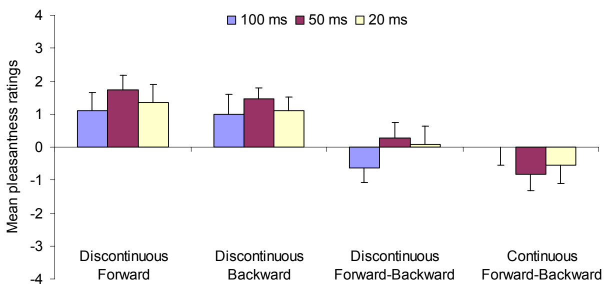

Figure 3. Mean ratings and S.E.M. for pleasantness of the stimuli.

For the ratings of arousal (see Figure 4), a two-way 4 × 3 (rotation style × burst length) ANOVA showed a statistically significant main effect of the rotation style $F(3, 30) = 11.2$, $p < 0.001$. The main effect of the burst length and the interaction of the main effects were not statistically significant. Post hoc pairwise comparisons showed that participants evaluated continuous forward-backward stimuli as significantly more arousing than discontinuous forward $MD = 2.1$, $p < 0.05$ and discontinuous backward $MD = 2.0$, $p < 0.01$ stimuli. The other pairwise comparisons were not statistically significant.

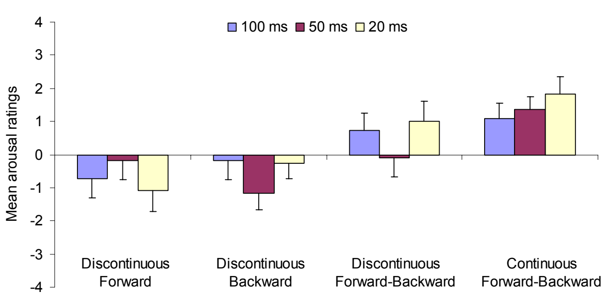

Figure 4. Mean ratings and S.E.M. for arousal of the stimuli.

For the ratings of approachability (see Figure 5), a two-way 4 × 3 (rotation style × burst length) ANOVA showed a statistically significant main effect of the rotation style $F(3, 30) = 6.4$, $p < 0.01$. The main effect of the burst length and the interaction of the main effects were not statistically significant. Post hoc pairwise comparisons showed that participants evaluated discontinuous forward stimuli as significantly more approachable than continuous forward-backward stimuli $MD = 1.8$, $p < 0.05$. The other pairwise comparisons were not statistically significant.

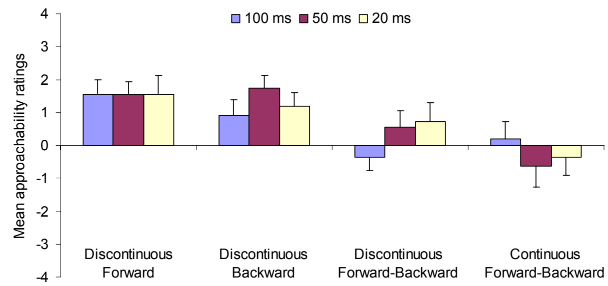

Figure 5. Mean ratings and S.E.M. for approachability of the stimuli.

For the ratings of dominance (see Figure 6), a two-way 4 × 3 (rotation style × burst length) ANOVA showed a statistically significant main effect of the rotation style $F(3, 30) = 14.3$, $p < 0.001$. The main effect of the burst length and the interaction of the main effects were not statistically significant. Post hoc pairwise comparisons showed that participants evaluated continuous forward-backward stimuli as significantly more dominant than discontinuous forward $MD = 2.3$, $p < 0.001$ and discontinuous backward $MD = 1.8$, $p < 0.05$ stimuli. The other pairwise comparisons were not statistically significant.

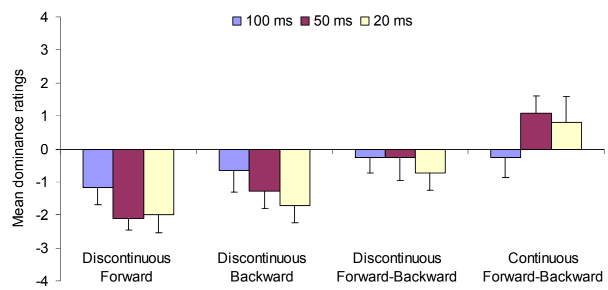

Figure 6. Mean ratings and S.E.M. for dominance of the stimuli.

Reaction Times

For the reaction times (see Figure 7), a two-way 4 × 3 (rotation style × burst length) ANOVA showed a significant interaction effect between rotation style and burst length $F(6, 60) = 7.0$, $p \leq 0.001$. It can be seen from Figure 7 that the interaction was due to the fact that participants reacted faster to stimulus pairs containing discontinuous forward stimuli with long bursts than to stimulus pairs containing discontinuous forward stimuli with short bursts and the other way around when rotation style was continuous forward-backward.

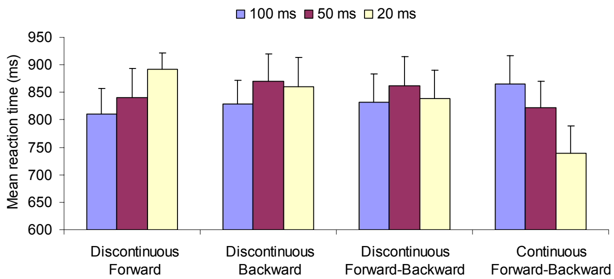

Figure 7. Mean reaction times and S.E.M. in distinguishing sequential stimuli as the same or different.

To analyze these effects in more detail two separate one-way ANOVAs were performed. One-way ANOVAs revealed a significant effect of the rotation style $F(3, 30) = 7.0$, $p \leq 0.001$, but the effect of the burst length was not statistically significant. Post hoc pairwise comparisons showed that participants reacted significantly faster to stimulus pairs that contained stimuli with continuous forward-backward rotation style than discontinuous forward $MD = 48.7$, $p < 0.05$ and discontinuous backward $MD = 34.5$, $p < 0.01$ rotation style. The other pairwise comparisons were not statistically significant.

Error Percentages

The overall error rate in distinguishing sequential stimuli as the same or different was 13 %.

For the error rates (see Figure 8), a two-way 4 × 3 (rotation style × burst length) ANOVA showed a significant interaction effect between rotation style and burst length $F(6, 60) = 7.5$, $p < 0.001$. The interaction was due to the fact that participants reacted more accurately to stimulus pairs containing discontinuous forward stimuli with long bursts than to stimulus pairs containing discontinuous forward stimuli with short bursts and the other way around when the rotation style was continuous forward-backward.

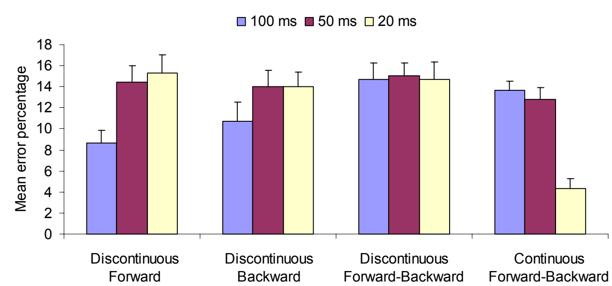

Figure 8. Mean error percentages and S.E.M. in distinguishing sequential stimuli as the same or different.

To analyze these effects in more detail two separate one-way ANOVAs were performed. One-way ANOVAs showed a significant effect of the rotation style $F(3, 30) = 7.2$, $p \leq 0.001$. Post hoc pairwise comparisons showed that participants reacted significantly more accurately to stimulus pairs containing continuous forward-backward than discontinuous forward-backward stimuli $MD = 4.5$, $p < 0.01$. The other pairwise comparisons were not statistically significant. One-way ANOVAs showed also a significant effect of the burst length $F(2, 20) = 4.5$, $p < 0.05$. Post hoc pairwise comparisons showed that participants reacted significantly more accurately to stimulus pairs containing stimuli with 20 ms long bursts as compared to stimuli with 50 ms long bursts $MD = 2.6$, $p < 0.05$. The other pairwise comparisons were not statistically significant.

DISCUSSION AND SUMMARY

Our results showed that ratings using four centrally emotion related bipolar scales were significantly affected by the haptic stimuli used in the experiment. The findings revealed that rotation style was coherently the variable that was related to changes in the ratings. In general, for each of the rating scales, the findings showed a clear main effect of rotation style (i.e., discontinuous vs. continuous stimuli). Furthermore, post hoc pairwise comparisons showed clear, coherent, and statistically significant differences so that discontinuous stimuli were rated as more pleasant and approachable but less arousing and dominating than continuous stimuli. The reaction time and error rate analyses showed that for reaction times the most significant variable was again the rotation style although we found that the error rates were also affected by the burst length. In generalizing the findings from reaction times and error rates, we found that forward rotating discontinuous stimuli were processed fully contrary to continuous forward-backward stimuli. Stimuli consisting of the longest (i.e., 100 ms) burst lengths were reacted the fastest and the most accurately when the rotation style was discontinuous forward. On the other hand, stimuli consisting of the shortest (i.e., 20 ms) burst lengths were reacted the fastest and the most accurately when the rotation style was continuous forward-backward.

Looking from the perspective of human-technology interaction, it is clear that research and development of haptic devices and haptic interaction is a very promising field of research. So far it seems that most of the work on the haptic emotional interaction has concentrated on creating prototype systems and then building up stimuli for them. After that the recognition of preplanned stimuli has been studied [e.g., 5,6,7,22]. In this perspective our study parallels to the earlier work. First, we devised a prototype and then found that the stimuli given with it were identified or distinguished from each other relatively well. This type of work that could be called more cognitively driven research is very much needed in the area of sense based artificial informing, messaging, or communication.

On the other hand there appears to be quite strong motivation to create and implement haptic applications related to social and emotional stimulation or communication. However, at present this development seems to be in its early phases. Some device prototypes like the LumiTouch [8], the Hapticat [36], the TapTap [3], and the Hug [10] have been developed but there is not yet much of evidence that they, in fact, mediate or evoke such emotional reactions that researchers have aimed at. We note that it may well be the case that all kinds of haptic stimuli can carry two types of information in similar fashion than facial information that can contain information both about ones identity (cognitive information) and emotional state (emotional information). In a larger context, this view is related to theories of human cognition and emotion [e.g., 20].

We used an approach that is very familiar from a mass of basic emotion research [e.g., 1,4,9]. Participant's responses were investigated by asking the ratings of their emotional experiences of the used stimuli. In a way this type of research is "user centered" because there are no researchers' preconceptions involved in the used stimuli. We found hints of emotion-cognition interaction by showing that continuous stimuli which were rated as more unpleasant, more arousing, dominating, and less approachable were also reacted faster and less erroneously than discontinuous stimuli which were rated as more pleasant.

We have earlier shown experimental evidence about the significant modulation of cognitive performance by positive and negative emotional messages (i.e., emotion-cognition interaction) in different types of problem solving tasks in human-computer interaction [2,25]. Although these studies are not fully comparable to the present study, we can see that emotional factors are inherently important in interaction with technology. Thus, in addition to measurement of cognitive variables like recognition, identification, or discrimination, it is equally important to trace emotional factors.

The dimensional view on emotions [e.g., 4] used in this study seems to be one promising way to take the first steps when studying social-emotional communication cues for haptics. As the current findings turned out to be significant, the following steps for us will include measurements of more low level signals like autonomic nervous system responses [e.g., 1,2], and facial electromyographic responses [e.g., 25].

In summary, we can clearly suggest that if one wants to utilize our findings in planning haptic stimulation that evokes user's attention, it is better to use continuous than discontinuous stimulation. We know now that continuous stimulation, even though not experienced very pleasantly, draws the attention by being more dominating as well as more arousing. It can also make one react more quickly and accurately. These qualities can be utilized, for example, to alert about high priority events when working in visually overloaded environments.

ACKNOWLEDGEMENTS

This research is a part of Mobile Haptics project funded by the Finnish Funding Agency for Technology and Innovation, (Tekes) (decision number 40219/06). For more information of the project, please visit http://mobilehaptics.cs.uta.fi/en.

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