# Evaluating the Effect of Temporal Parameters for Vibrotactile Saltatory Patterns

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## ABSTRACT
Cutaneous saltation provides interesting possibilities for applications. An illusion of vibrotactile mediolateral movement was elicited to a left dorsal forearm to investigate emotional (i.e., pleasantness) and cognitive (i.e., continuity) experiences to vibrotactile stimulation. Twelve participants were presented with nine saltatory stimuli delivered to a linearly aligned row of three vibrotactile actuators separated by 70 mm in distance. The stimuli were composed of three temporal parameters of 12, 24 and 48 ms for both burst duration and inter-burst interval to form all nine possible uniform pairs. First, the stimuli were ranked by the participants using a special three-step procedure. Second, the participants rated the stimuli using two nine-point bipolar scales measuring the pleasantness and continuity of each stimulus, separately. The results showed especially the interval between two successive bursts was a significant factor for saltation. Moreover, the temporal parameters seemed to affect more the experienced continuity of the stimuli compared to pleasantness. These findings encourage us to continue to further study the saltation and the effect of different parameters for subjective experience.

## Categories and Subject Descriptors
H.5.2 [**Information Interfaces and Presentation**]: User Interfaces – *Evaluation/methodology, Haptic I/O.*

## General Terms
Experimentation, Human Factors, Measurement, Design.

## Keywords
Haptics, vibrotactile patterns, cutaneous saltation, human-technology interaction


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## 1. INTRODUCTION
The usefulness of haptic feedback in information presentation and different notification systems has been largely acknowledged. Of all the technologies available, vibrotactile actuators are the most commonly used due to their relatively low price, simple control mechanisms, and good portability. There are many types of actuators that can be used to generate vibration including, for example, piezoelectric actuators, pneumatic valves and the widely used miniature DC motors with a rotating unbalanced weight. One of the most interesting technologies that has a reasonably good performance and that is very simple to control is a linear voice-coil type actuator, similar to those used in conventional audio speakers. These actuators provide better control together with more accurate temporal timing compared to the rotating motors. They can also be driven by a regular audio signal and amplifier making their use rather straightforward.

Most of the earlier vibrotactile information presentation systems have been concentrating on the hand (e.g., [4]). One classic example is a standard mobile phone that has a vibrating motor embedded causing the whole device to resonate when, for example, an SMS is received or a notification is launched. Recently, there have been emerging other kind of mobile devices utilizing the illusion of localized feedback felt under the finger touching the screen. Using palms and fingers is quite logical as they are normally used for exploring and manipulating the environment. Some studies have introduced wearable devices integrated in, for example, a scarf providing a comforting tap of vibration to the shoulder of a user [1] or a jacket capable of generating tactile patterns enriching a movie experience [10]. These multiactuator solutions use larger body areas that make it a more natural method to provide emotion related messages or expressions.

As we are interested mostly in the emotional side of communication we decided to study a wearable device attached to the forearm. The device itself is quite close to what has been previously used by Brown *et al*. [3] where three actuators were placed along the forearm. However, while they used stimuli that had three dimensions of an alert coded by rhythm, roughness, and location of stimulation, we make use of a perceptual illusion called *cutaneous saltation*.

Since being found in the early 1970s [7] cutaneous saltation has become one of the most intriguing tactile phenomena. An initial setup that led to its discovery had three actuators placed linearly on the forearm with equal distances. To trigger off the sensation three brief bursts were delivered to each actuator location starting from the one closest to the wrist and ending at the actuator farthest away from the wrist. Instead of feeling the successive taps fixed at the three actuator locations participants were under the impression that the pulses felt to distribute with more or less uniform spacing between the actuators traveling away from the wrist. This phenomenon was immediately separated from that of *apparent movement* [7] that had been widely known since the early 20th century. Both of these phenomena are dependent on both the equal temporal spacing between two successive bursts (i.e., inter-burst interval, IBI) and the duration of a single burst (i.e., burst duration, BD). The main difference between these two perceptual illusions of movement lies in the sensation they produce: the saltation occurs as an easily perceptible train of pulses whilst the apparent movement generates more faint feeling of movement. The work by Geldard [8] creditably covers most of the cutaneous saltation while those interested in apparent motion should see for, for example, Sherrick [15] for more information.

Although there is a range of studies on the optimal parameters for cutaneous saltation and the circumstances where it appears (e.g., [7], [8], and [5]), there is still an obvious need for systematic research on the effect of different parameters for saltation. Especially the components affecting the emotional loading of the phenomenon have practically not been studied at all. The closest to this has been a study by Cholewiak & Collins [5] where they asked the participants to judge the perceived length, smoothness, spatial distribution, and straightness of two separate presentation modes: saltatory with three and veridical (i.e., sequentially actuated) with seven evenly spaced locations of stimulation. The sites were arranged so that the same linear array of seven actuators was used in both cases while only the first, fourth, and seventh was actuated in the saltatory mode. With this setup they were able to filter out certain IBI and BD ranges for each of the measured qualities.

Dimensional affective space has been shown to be a viable method to collect emotional responses of the participants. It has been lately found out that certain tactile stimuli are associated to human emotions [11], [14]. A study by Salminen *et al*. [14] concluded that the tactile stimuli rated as arousing were also rated as unpleasant and, vice versa, the relaxing stimuli were rated as pleasant. A more recent study by Lylykangas *et al*. [11] suggests that otherwise parametrically equivalent vibrotactile stimuli composed of sine wave are evaluated as more arousing compared to those composed of sawtooth wave. However, there were no such differences in the pleasantness ratings between the two waveforms used in their study. Whether the ambivalence in the results of these two studies depends on the location of stimulation (fingertip vs. wrist and chest), the tactile technology used (i.e., a rotating fingertip stimulator vs. linear vibrotactile actuator), or something else cannot be said. Nevertheless, it points out that there is still plenty of room for new studies on the relationship between emotions and tactile stimulation.

To study the emotional aspect of cutaneous saltation, we decided to run an experiment to find out if a limited set of saltatory stimuli would project as distinct subjective evaluations. We decided to use the subjective rating scales for pleasantness that has also been used in several earlier studies (e.g., [2], [14], and [11]). In addition, we also measured the continuity of the movement because we were interested whether it would correlate with the pleasantness. The temporal parameters used in our experiment were based on both the rough limits provided by Cholewiak & Collins [5] and our own pilot studies.

# 2. METHODS

## 2.1 Participants

Twelve voluntary participants (11 males, 1 female) took part in the experiment (mean age 24.6 years, range 20–34 years). All the participants were right-handed and had a normal sense of touch by their own report. None of the participants had previously attended similar studies nor were familiar with the illusion of cutaneous saltation.

## 2.2 Apparatus

A PC computer with Windows XP Professional and the standard Microsoft USB Audio Device driver was used to play three-channel (32-bit float Microsoft WAVEX) audio files through an external USB sound card (Audiotrak Maya EX5 CE[1]). The audio files were generated with the Audacity open source audio software[2]. A SM Pro Audio HP4V headphone amplifier[3] based on NJM4558D circuits was used to amplify the signals from the soundcard.

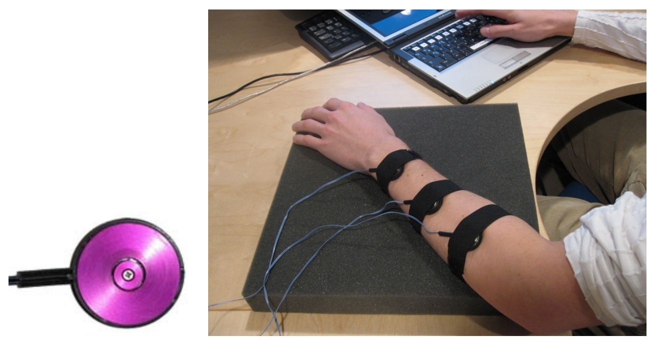

**Figure 1. A picture of the C-2 actuator used in the study (on the left) and a snapshot of experimental setup (on the right).**

Three C-2 linear vibrotactile voice coil actuators (Engineering Acoustic Inc.[4]) were used to present vibrotactile stimuli. The diameter of a single C-2 actuator was 3.05 cm (1.2"), and the diameter of the vibrating skin contactor in the middle of the actuator area was 0.76 cm (0.3"). The actuators were fastened one by one to the dorsal (i.e., hairy) side of the left forearm with elastic and adjustable Velcro straps. In addition, the actuators were also fixed to the straps using small pieces of self-adhesive Velcro band to avoid them to move during the experiment. The middle actuator was attached first longitudinally at the center of the forearm after which the two outer ones were attached 70 mm (2.8") away from it measured from the center of the actuators. Thus, the total length of the display was 140 mm measured from center to center. The firmness of the attachment was controlled by the same experimenter for every participant but it was not measured. The C-2 actuator and the experimental setup are illustrated in Figure 1.

[1] http://www.audiotrak.net/

[2] http://audacity.sourceforge.net/

[3] http://www.smproaudio.com/

[4] http://www.eaiinfo.com/

A custom programmed VB.NET application was used both to control the stimulus presentation and to collect the data. BASS audio library[5] with BASS.Net API 2.4.2.0 was used with MS Visual Studio 2005 to implement the experimental software. Responses were given with a keyboard of a standard laptop (Samsung NP-Q35) where the numeric keys from 1 to 9 were labeled as a continuous scale of "-4..0..+4", respectively, for the evaluation block. The space bar was labeled as "Select" for the ranking block and for general proceeding in the experiment. The other keys were not labeled and were disabled by the program.

## 2.3 Stimuli

The stimuli were designed to be generally favorable for the cutaneous saltation on the forearm region. Three different burst durations (BD) and inter-burst intervals (IBI) of 12, 24, and 48 ms were used to design the stimuli. All possible combinations of these two parameters were used resulting in a total of nine different stimuli. By design, the stimuli can divided into three groups based on the mutual relation of the parameters where BD is either smaller, equal or larger compared to IBI. The temporal parameters of the stimuli were selected based on the previous literature [5], and further refined in the pilot studies. The frequency of the stimuli was constant 250 Hz which is commonly considered the most detectable band for the human sense of touch and is also the optimal frequency of the C-2 actuators.

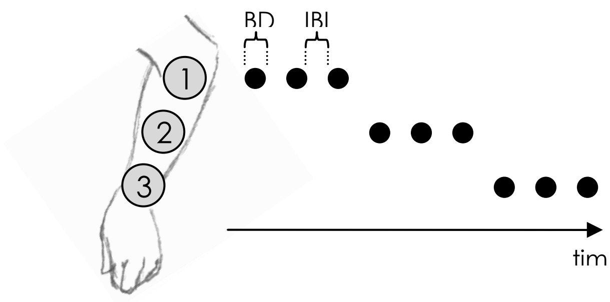


**Figure 2. The spatiotemporal vibrotactile sequence used in the experiment. The black circles represent vibrotactile bursts.**

Stimulus amplitude was adjusted to about 500 mV (AC) for all three channels (i.e., actuators) by measuring the voltage from the amplifier outputs with a Fluke® 87 V True RMS multimeter[6] while the actuators were playing a constant 250 Hz sine wave calibration stimulus. This amplitude was piloted to be suitable to successfully evoke the saltation. A sinusoidal waveform was used in the stimulus design because it has been suggested to generate more gentle saltatory effect [8].

A classic saltatory stimulation method was used where three individual pulses were presented successively starting from the actuator closest to the elbow and continuing distally towards the one closest to the wrist (see Figure 2). Eventually, the participants felt a number of pulses to spread evenly between the most proximal and distal actuators. The exact durations for each stimulus depended on the BD and IBI ranging from 204 ms (9 × 12 ms + 8 × 12 ms) to 816 ms (9 × 48 ms + 8 × 48 ms) (see Table 1 for all stimulus durations).

**Table 1. The parameters of burst duration (BD) and inter-burst interval (IBI) for each stimulus with resulting total stimulus duration.**

| Index | BD (ms) | IBI (ms) | Duration (ms) |
|---|---|---|---|
| 0 | 48 | 48 | 816 |
| 1 | 48 | 24 | 624 |
| 2 | 24 | 48 | 600 |
| 3 | 48 | 12 | 528 |
| 4 | 12 | 48 | 492 |
| 5 | 24 | 24 | 408 |
| 6 | 24 | 12 | 312 |
| 7 | 12 | 24 | 300 |
| 8 | 12 | 12 | 204 |

## 2.4 Procedure

First, the participant was introduced with the laboratory and the equipment used in the experiment. Then, the participant was seated and provided with general information about the experiment and the procedure, and the actuators were attached on the dorsal side of the forearm of the left hand with the elastic straps matching the individual dimensions of the arm. The left hand was instructed to be kept on the table on top of a piece of foamed plastic and the other hand was put next to the keyboard with the response buttons. The participant was instructed to hold the left hand still and to concentrate on the stimuli presented while listening to low-amplitude pink noise using a hearing protector headset to block the mechanical noise of the actuators.

The experiment consisted of two separate sessions: ranking and rating. The same nine stimuli were used in both sessions. The order of the sessions was not counterbalanced between the participants but carried out in aforementioned order. Thus, the purpose of the ranking session was twofold: it was used both as a separate measure to rank the stimuli using the two measured dimensions (i.e., continuity and pleasantness) and to familiarize the participants with the stimulus space. Within both sessions the participants were instructed to either rank or rate the presented stimuli in two blocks, one for continuity and one for pleasantness of the stimuli. The order of the continuity and pleasantness blocks was counterbalanced between the participants but kept the same within a single participant for each session and block. The order of the stimuli was randomized for each participant, session, and block. The experimental software provided the necessary guidance throughout the session and offered the participants an opportunity to rest between the blocks.

### *2.4.1 Stimulus ranking*

In the beginning of the first session the ranking procedure and the scales of the continuity and pleasantness blocks were explained to the participants. Then they were presented with three practice trials for both blocks where three practice stimuli were ranked similarly to the actual experiment. The practice stimuli were not presented in the actual experiment but were selected so that also they evoked a saltatory pattern. After the practice the experimenter left the room having ensured that the participant understood the task and that the saltatory movement was present and traveled to the right direction

[5] http://www.un4seen.com/

[6] http://www.fluke.com/

along the arm. After this the participant was allowed to start the first trial.

In a trial, the participants initiated the task by pressing the space bar after which the application waited for 3 seconds before three circles representing the three trial stimuli appeared on the screen. The stimuli were presented sequentially with an onset interval of 3000 ms and the currently active circle was being highlighted from left to right for 1500 ms from the onset of the stimulus. After the third (i.e., rightmost) stimulus the sequence started over. The task was to filter out the most continuous or pleasant stimulus first by pressing the space bar labeled as “Select”. After ranking the first stimulus the corresponding circle was dimmed and the program continued to present the two remaining stimuli until the participant filtered out the second one leaving the final one out of the selection. This procedure was carried out three times for each three rounds to rank all the stimuli.

Using this method, on the first round, the stimulus set that was randomized into three groups was ranked. On the second round, the three stimulus groups were reorganized so that the new groups consisted of the three stimuli that were ranked the first (i.e., “firsts”), the second (i.e., “seconds”) and those that were left out (i.e., “left outs”), all in their separate groups. The stimuli within each group were randomized and ranked again. On the third round there were three steps: First, the one ranked the best out of the group of the “firsts” was stored and the two other together with the one ranked the best out of the “seconds” were again ranked in a randomized order. Second, the one ranked the best out of the latter group was again stored and the remaining two plus the best of the initial “left outs” group was ranked. This method was deduced to filter out a mathematically valid group of three stimuli that were ranked the best out of the original set of nine. Third, this filtered group was once more ranked to find out the final order of the three stimuli. The same procedure was run for both blocks separately and the participants were provided with an option to rest after having ranked three groups of stimuli (i.e., one round) as well as between the blocks (i.e., continuity and pleasantness ranking).

### *2.4.2 Stimulus rating*

In the second session the participant was instructed to rate the subjective experiences evoked by the stimuli using two nine-point bipolar scales varying from -4 to +4. The scale of the continuity of the stimulus varied from discontinuous to continuous and that of pleasantness varied from unpleasant to pleasant. On both scales 0 in the middle represented a neutral experience (i.e., neither discontinuous nor continuous and neither unpleasant nor pleasant). The ratings were given using a computer keyboard with nine adjacent keys labeled from -4 to +4, horizontally.

In the beginning of the session the rating procedure and the scales for continuity and pleasantness were explained to the participants. The participants were then presented with three practice trials for both scales separately in a similar order to the experiment. The practice stimuli were not presented in the actual experiment but were the same as in the previous session. After the practice trials, the experimenter left the room and the participant was allowed to start rating the experimental stimuli.

In both blocks the participant was presented with three sets of nine stimuli sequentially with the interval of 3 seconds between the given response and the stimulus onset. Reaction time was not measured for the responses. The participants were provided with an option to rest between each set of nine stimuli as well as between the blocks.

In both blocks (i.e., continuity and pleasantness) each of the 9 stimuli were presented three times in a randomized order. Thus, there were a total of 54 trials for rating.

## 2.5 Data Analysis

The experiment was a within-subject 3 × 3 (burst duration × inter-burst interval) design. In ranking, for each participant and block the three best stimuli were assigned numbers from 1 to 3 and the other six stimuli were assigned with a number 4. A non-parametric Friedman’s rank test was used for statistical analysis of the ranking data and Wilcoxon signed-rank tests were used for pairwise comparisons of results within each task.

Repeated measures analysis of variance (ANOVA) was used for statistical analysis of the rating data. If the sphericity assumption of the data was violated, Greenhouse-Geisser corrected degrees of freedom were used to validate the respective $F$ statistic. Bonferroni corrected pairwise $t$-tests were used for post hoc pair-wise comparisons.

# 3. RESULTS

## 3.1 Ranking

### *3.1.1 Continuity*

Frequencies for continuity ranking of the stimuli are presented in Figure 3. The Friedman test revealed an effect that approached statistical significance for stimulus ($X^2 = 14.706$, $p = .054$).

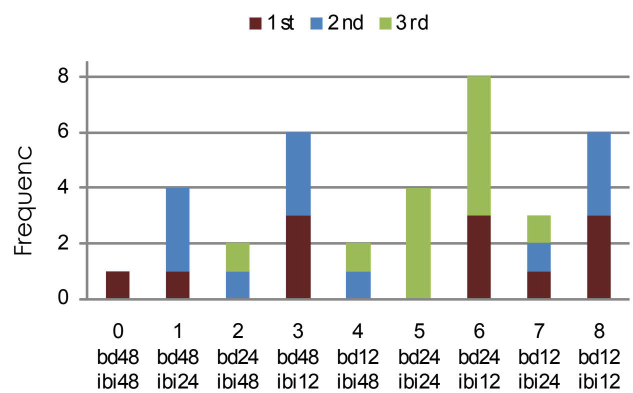


**Figure 3. Frequencies for continuity ranking of the saltatory stimuli ($n = 36$).**

The Friedman test showed a statistically significant effect for IBI ($X^2 = 9.783$, $p < .01$) for the continuity ranking of the stimuli (Figure 4). The effect for BD was not statistically significant. Wilcoxon pairwise comparisons indicated that the participants ranked the continuity of the stimuli with 12 ms IBI significantly higher compared to those with 24 ms intervals ($Z = -2.188$, $p < .05$). Mean of the ranks was 4.25 in favor of 12 ms and 6.39 in favor of 24 ms intervals. The stimuli with 12 ms intervals were also ranked higher than those with 48 ms intervals ($Z = -2.792$, $p < .01$) with corresponding mean ranks of 1.75 and 7.45. The difference between 24 and 48 ms intervals was not significant. The post hoc comparisons for BD showed no significant pairwise differences.

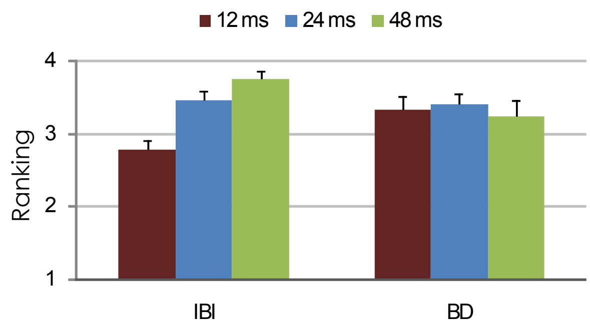


**Figure 4. The mean rankings and standard error of the means (S.E.M.s) for continuity presented by the temporal parameters (the smaller the better).**

### *3.1.2 Pleasantness*

Frequencies for pleasantness ranking of the stimuli are presented in Figure 5. The Friedman test indicated no significant effect for stimulus.

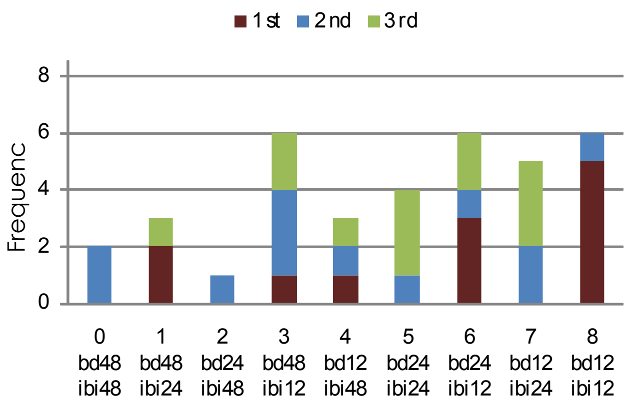


**Figure 5. Frequencies for pleasantness ranking of the saltatory stimuli (*n* = 36).**

The Friedman test showed a statistically significant effect for IBI ($X^2$ = 6.978, $p < .05$) for the pleasantness ranking of the stimuli (Figure 6). The main effect for BD was not statistically significant. Wilcoxon pairwise comparisons indicated that the participants ranked the pleasantness of the stimuli with 12 ms IBI significantly higher compared to those with 48 ms intervals ($Z = -2.124$, $p < .05$) with corresponding mean ranks of 6.00 and 6.60. The difference between stimuli with 12 ms and 24 ms intervals approached significant ($Z = -1.964$, $p = .53$) with mean ranks of 3.67 and 6.88. The difference between 24 and 48 ms intervals was not significant. The post hoc comparisons for BD showed no significant pairwise differences.

## 3.2 Rating

### *3.2.1 Continuity*

A one-way repeated measures ANOVA revealed a statistically significant main effect ($F(8) = 5.969$, $p < .01$) for the continuity rating of stimulus (Figure 7). Post hoc pairwise comparisons showed significant differences in continuity ratings between stimuli 0 and 1 (MD = 1.389, $p < .01$) the latter being rated significantly more continuous.

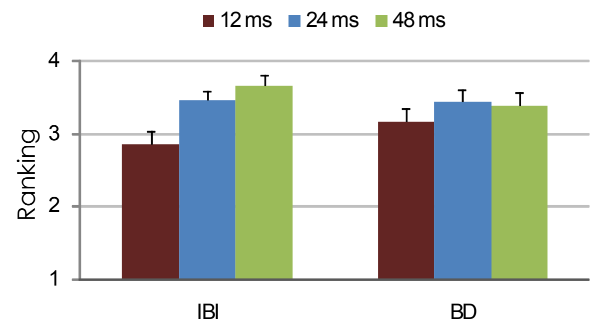


**Figure 6. The mean rankings and standard error of the means (S.E.M.s) for pleasantness presented by the temporal parameters (the smaller the better).**

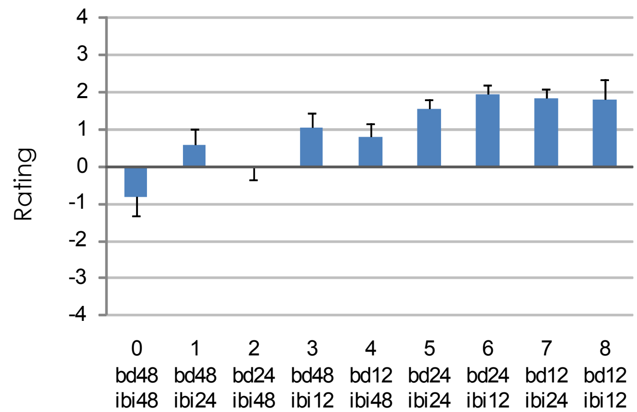


**Figure 7. The mean ratings and standard error of the means (S.E.M.s) for continuity of the stimuli.**

A two-way 3 × 3 (IBI × BD) ANOVA revealed a statistically significant main effect for both IBI ($F(1, 11) = 10.169$, $p < .01$) and BD ($F(2) = 5.100$, $p < .05$) of the stimuli (Figure 8). There was no statistically significant interaction between IBI and BD. Post hoc pairwise comparisons showed that the stimuli with 48 ms IBI were rated significantly less continuous compared to those with both 24 ms ($MD = -1.315$, $p < .001$) and 12 ms ($MD = -1.593$, $p < .05$) intervals. The difference between 24 and 12 ms intervals was not significant. The post hoc comparisons for BD showed no significant pairwise differences.

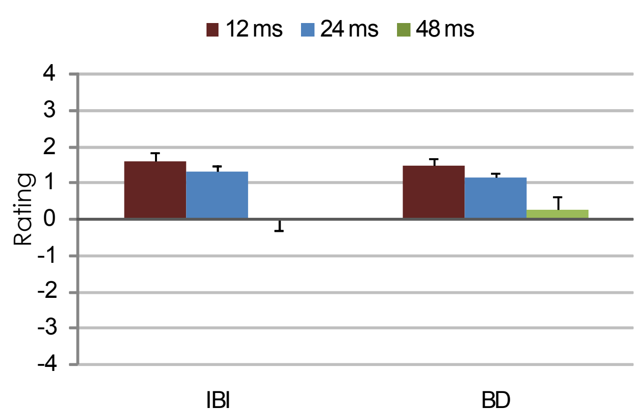


**Figure 8. The mean ratings and standard error of the means (S.E.M.s) for continuity presented by the temporal parameters.**

### 3.2.2 *Pleasantness*

A one-way repeated measures ANOVA indicated no statistically significant main effect for the pleasantness rating of stimulus (Figure 9). Post hoc pairwise comparisons showed no significant differences in the rated pleasantness between any two stimuli.

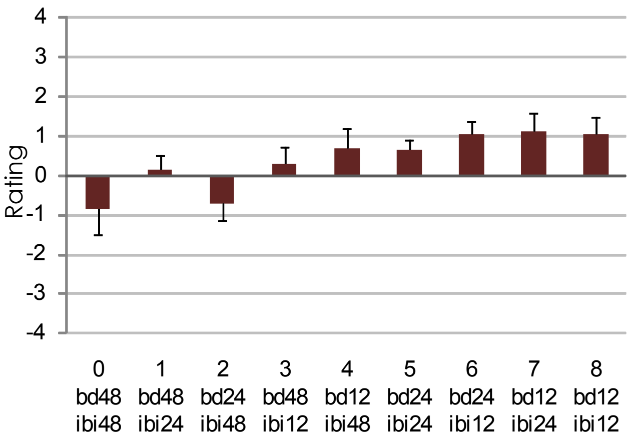


**Figure 9. The mean ratings and standard error of the means (S.E.M.s) for pleasantness of the stimuli.**

A two-way 3 × 3 (IBI × BD) ANOVA showed a statistically significant main effect for IBI ($F(1, 11) = 5.000$, $p < .05$) of the stimuli (Figure 10). The main effect for BD was not statistically significant nor was there any statistically significant interaction between IBI and BD. Post hoc pairwise comparisons showed no significant pairwise differences for pleasantness rating for neither IBI nor BD.

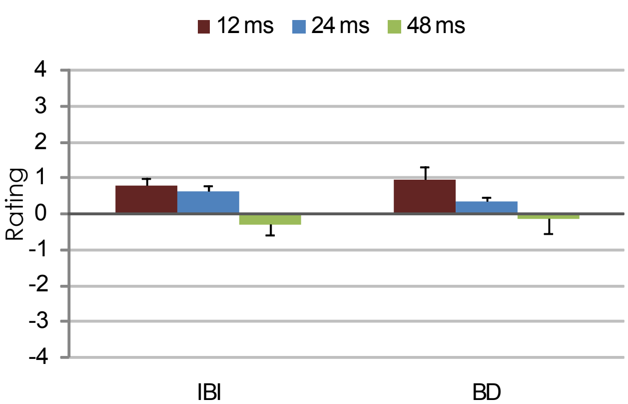


**Figure 10. The mean ratings and standard error of the means (S.E.M.s) for pleasantness presented by the temporal parameters.**

## 4. DISCUSSION

This study is the first investigation into the emotional aspects of vibrotactile saltation. The subjective rating scale of pleasantness was used to compare nine different saltatory patterns. The patterns were composed of three durations of 12, 24, and 48 ms that formed nine pairs (3 × 3) for the interval between two successive bursts of vibration and the duration of such a burst. To further evaluate the selected stimuli a rating scale of continuity was used as an additional measurement. To support the rating method that has successfully been used in earlier studies (e.g., [2], [11], and [14]), we designed a method on our own where the saltatory stimuli were systematically ranked to filter out the three most continuous and pleasant ones. These two methods provided slightly different approaches: in the rating the stimuli were rated individually one by one while in the ranking three stimuli at a time were directly compared to each other providing us with the ranking order of the three most continuous or pleasant stimuli. Interestingly, both methods provided analogous results indicating that participants evaluated the stimuli consistently regardless of the method used.

The ratings (Figure 8) show that the IBI and BD both had an effect on the rated continuity but that of IBI was somewhat greater. The stimuli with the shorter 12 and 24 ms intervals were rated clearly more continuous compared to the longer 48 ms interval. For the continuity rating of BD a similar but not as clear tendency was present. The method of ranking further confirms the strong effect of IBI for the perceived continuity, especially with the 12 ms interval (see Figure 4). IBI was found to be a major factor also for the rated pleasantness of the stimuli (Figure 10). Even though the longer interval was, again, rated lower compared to the shorter ones the difference was still not as clear as for the continuity. The role of IBI was further supported by the pleasantness ranking (Figure 6).

Most of the participants thought that being a more concrete concept the continuity was easier to judge compared to pleasantness. The results support this statement as the differences in both stimulus ratings and rankings were less obvious for the scale pleasantness. Thus, it seems that such small differences in temporal parameters can be reliably evaluated for continuity but possibly not for pleasantness. On the other hand, pleasantness is a highly subjective experience where variability is even expected due to individual preferences. We suggest that more diverse temporal parameters should be used if saltatory patterns with different levels of pleasantness are required. Alternatively, other parameters, such as, amplitude, frequency, or waveform of stimulation could affect more on the pleasantness. It is quite probable that being a temporal scale, continuity is more dependent on the temporal parameters studied here.

It is not known how the emotional ratings of cutaneous saltation are affected by, for example, different waveforms and frequencies. Geldard [8] described that the saltation evoked by square waves "feels sharp and bright" where as haversine signals generates a "relatively dull thud". How is this with more complex signals? The same source suggests that higher frequencies are felt as sharper stimulation whereas the lower frequencies evoke a duller saltation. Geldard [6] stated that for apparent movement the otherwise identical stimuli were judged to move faster when a lower amplitude was applied compared to the higher one. In his study on the saltation Geldard [8] stated that amplitude had an effect on the length of the perceived spatial distribution of saltation making the leaps longer. However, Geldard continued that the effect of amplitude is dominated by that of the temporal parameters. Based on our results, it can be speculated that the shorter IBI and BD could make the saltatory pattern feel less intense and thus more pleasant. To further study the emotion related responses a larger set of scales should be used as the dimensional affective space maps emotions as combinations of two or more dimensions [2]. In addition to pleasantness (i.e., valence), the dimensions of arousal, dominance, and approachability have been used in the earlier studies [2], [11], and [14].

Another topic worth studying is the comparison of cutaneous saltation and apparent movement in the sense of emotional dimensions. Cholewiak and Collins [5] scratched the topic in their study the results of which indicated that the veridical and saltatory modes provide equivalent sensations. However, the temporal parameters used in the study did not favor the illusions. Cutaneous saltation has previously been mostly used to provide intuitive navigational information. Tan *et al*. [16] first introduced a three by three matrix of vibrotactile actuators attached to the back of a chair. The device was used to provide both attentional and directional information. The results of the study suggest that the device could successfully be used for both usages. In another study Jones and Ray [9] compared a linear array of eight actuators mounted around the waist to a four by four actuator matrix on the back. While both of them had high response rates it was found that the waist display performed even better.

Most research on vibrotactile communication has been focusing on creating vibrational icons that represent a predefined meaning (e.g., [3]). These static icons may be efficient in delivering cognitive information but they do not provide enough freedom for delivering dynamic information, such as emotional expressions. Chang *et al*. [4] described a design for a device that could be used to communicate with an audio-tactile encoding system close to that of the Morse code. The scarf designed by Bonanni *et al*. [1] is another example of a multi-actuator wearable device that can provide some simple touch-like feedbacks to be mediated. Another interesting solution is a tactile jacket by Lemmens *et al*. [10] that uses 64 actuators distributed into separate segments to be able to provide different shapes and patterns using cutaneous saltation. This output device is designed to enrich a movie experience but it inspires interesting thoughts if used as a haptic communication device.

It seems that a wearable device could provide a more natural way to present emotions. Our results and those of the earlier studies presented above suggest that vibrotactile feedback can be used to communicate emotions. Oakley *et al*. [12] stated that a forearm mounted display is an appealing idea as it is easily accessible both physically and visually, and it is a generally acceptable location to wear an electronic device. Piateski and Jones [13] argue that the lower back is a superior location for recognition of two-dimensional saltatory patterns compared to the forearm. However, the actuators, frequencies and setups for these locations were so different that a trustworthy comparison cannot be made.

The aim of this study was to study how the temporal parameters of saltatory stimuli affect subjective experiences of continuity and pleasantness. The results can be used to enrich communication in the wearable devices similar to Bonanni *et al*. [1] and Lemmens *et al*. [10]. The importance of a short IBI for saltation would appear axiomatic as a stimulus with shorter period of pause between the bursts would likely result less sporadic and thus more smoothly progressive stimulation. However, based on the earlier studies cutting either of the temporal parameters too heavily would lead to losing the saltation effect. Thus, the parameters must be picked with care to optimize the illusion for specific purposes. While the effect of IBI and BD for the experienced continuity and pleasantness of saltatory stimulus certainly is an advantageous result, it alone does not provide us enough information to create emotional messages of different characteristics.

# 5. CONCLUSIONS

The experiment presented in this paper appears to be the first systematic empirical study on the emotional aspects of cutaneous saltation. The subjective experiences on the continuity and pleasantness were studied with a limited set of saltatory stimuli. The results suggest that both of the used scales of continuity and pleasantness were coherently used in judgments between the stimuli. A temporal parameter of inter-burst interval appeared to be the more determining parameter compared to the duration of a single burst. Two different evaluation methods, ranking and rating, were used to enable more thorough investigation over the temporal parameters. As both of the methods produced consistent results, we suggest that either one of them can be used to measure subjective experiences on vibrotactile stimuli. The results of this initial study suggest that cutaneous saltation could be used to deliver emotional expressions. Further research is, however, needed to investigate the effect of multiple parameters for evaluated experiences.

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# 7. REFERENCES

[1] Bonanni, L., Lieberman, C., Vaucelle, J., and Zuckerman, O. 2006. TapTap: A Haptic Wearable for Asynchronous Distributed Touch Therapy. In Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (Montreal, Quebec, Canada, April 22-27, 2006). CHI '06. ACM, New York, NY, 580-585. DOI= http://doi.acm.org/10.1145/1125451.1125573

[2] Bradley, M. and Lang, P. J. 1994. Measuring emotion: The self-assessment manikin and the semantic differential. J Behav Ther Exp Psychiatry 25, 1 (Mar. 1994), 49-59.

[3] Brown, L. M., Brewster, S. A., and Purchase, H. C. 2006. Multidimensional Tactons for Non-Visual Infomation Display in Mobile Devices. In Proceedings of the 8th International Conference on Human-Computer Interaction with Mobile Devices and Services (Espoo, Finland, Sep. 12-15, 2006). MobileHCI 2006. ACM, New York, NY, 231-238. DOI= http://doi.acm.org/10.1145/1152215.1152265

[4] Chang, A., O'Modhrain, S., Jacob, R., Gunther, E., and Ishii, H. 2002. ComTouch: Design of a Vibrotactile Communication Device. In Proceedings of the 4th conference on Designing interactive systems: processes, practices, methods, and techniques (London, England, Jun. 25-28, 2002). DIS'02. ACM, New York, NY, 312-320. DOI= http://doi.acm.org/10.1145/778712.778755

[5] Cholewiak, R. W. and Collins, A. A. 2000. The generation of vibrotactile patterns on a linear array: influences of body site, time, and presentation mode. Percept Psychophys 62, 6 (2000), 1220-1235.

[6] Geldard, F. A. 1957. Adventures in Tactile Literacy. Am Psychol 12, 3 (Mar. 1957), 115-124.

[7] Geldard, F. A. 1975. Sensory Saltation: Metastability in the Perceptual World. John Wiley & Sons, New York.

[8] Geldard, F. A. 1982. Saltation in somesthesis. Psychol Bull 92, 1 (1982), 136-175.

[9] Jones, L. and Ray, K. 2008. Localization and Pattern Recognition with Tactile Displays. In Proceedings of the Symposium on Haptic Interfaces for Virtual Environment and Teleoperator Systems 2008 (Reno, NE, Mar. 13-14, 2008). HAPTICS 2008. IEEE Computer Society, Washington, DC, 33-39. DOI= http://dx.doi.org/10.1109/HAPTICS.2008.4479910

[10] Lemmens, P., Crompvoets, F., Brokken, D., van den Eerenbeemd, J., and de Vries, G.-J. 2009. A body-conforming tactile jacket to enrich movie viewing. In the Proceedings of the third joint Eurohaptics Conference and Symposium on Haptic Interfaces for Virtual Environment and Teleoperator Systems (Salt Lake City, UT, Mar. 18-20, 2009). WorldHaptics 2009. IEEE Computer Society, Washington, DC, 7-12. DOI= http://dx.doi.org/10.1109/WHC.2009.4810832

[11] Lylykangas, J., Surakka, V., Rantala, J., Raisamo J., and Raisamo R. 2009 Vibrotactile information for intuitive speed regulation. In the Proceedings of the 23rd BCS Conference on Human Computer Interaction, HCI 2009, 1-5 September 2009, Cambridge, UK, in press.

[12] Oakley, I., Kim, Y., Lee, J., and Ryu, J. 2006. Determining the Feasibility of Forearm Mounted Vibrotactile Displays. In Proceedings of the Symposium on Haptic Interfaces for Virtual Environment and Teleoperator Systems 2006 (Alexandria, VA, Mar. 25-29, 2006). HAPTICS 2006. IEEE Computer Society, Washington, DC, 27-34. DOI= http://dx.doi.org/10.1109/VR.2006.49

[13] Piateski, E. and Jones, L. 2005. Vibrotactile pattern recognition on the arm and torso. In the Proceedings of the first joint Eurohaptics Conference and Symposium on Haptic Interfaces for Virtual Environment and Teleoperator Systems (Pisa, Italy, Mar. 18-20, 2005). WorldHaptics 2005. IEEE Computer Society, Washington, DC, 90-95. DOI= http://dx.doi.org/10.1109/WHC.2005.143

[14] Salminen, K., Surakka, V., Lylykangas, J., Raisamo, J., Saarinen, R., Raisamo, R., Rantala, J., and Evreinov, G. 2008. Emotional and behavioral responses to haptic stimulation. In Proceeding of the Twenty-Sixth Annual SIGCHI Conference on Human Factors in Computing Systems (Florence, Italy, April 05-10, 2008). CHI'08. ACM, New York, NY, 1555-1562. DOI= http://doi.acm.org/10.1145/1357054.1357298

[15] Sherrick, C. E. 1968. Studies of apparent tactual movement. In D. R. Kenshalo (Ed.), The skin senses (pp. 331-344). Springfield, IL: Charles C. Thomas.

[16] Tan, H. Z., Gray, R., Young, J. J., and Traylor, R. 2003. A haptic back display for attentional and directional cueing. Haptics-e: The Electronic Journal of Haptics Research 3, 1 (Jun. 2003), 20 pp.