

## **DESIGN RECOMMENDATIONS FOR TACTONS IN TOUCH SCREEN INTERACTION**

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### **ABSTRACT**

Tactons are structured tactile messages and used to transmit information to users via the tactile sense. In recent studies, tactons were tested under various conditions and their benefits were demonstrated, while tactons were mostly applied on a non-interacting part of participants' body. In future applications, e. g. in touch screen interaction, the device itself will probably generate the tactile feedback providing it to the user's interacting finger. Therefore, common parameters (i. e., frequency, amplitude, rhythm, roughness, waveform, and duration) in such a setting were examined and tested for discriminability in order to derive guidelines for tacton design in touch screen interaction. 51 participants took part in the experiment, which consisted of 98 randomized tasks. In each task, participants were presented two vibration signals via a touch screen and had to decide, whether signals were identical or different. 87 tasks comprised a comparison between different signals, while only one parameter was altered in a single comparison, and 11 control pair signals were identical. The overall recognition rate was  $0.69 \pm 0.15$  but various combinations showed recognition rates above 90%. It became clear that some parameters are more suitable in tacton design than others. Frequency and roughness achieved the best results, involving all paired comparisons which were correctly distinguished by each participant. Distinguishable levels of parameters and design recommendations were derived from the experiment, and considerations about future tacton design are presented.

### **KEYWORDS**

Human-Machine Interaction, Tactile Feedback, Information Coding, Tacton Parameters

## **1. INTRODUCTION**

Touch screens are increasingly used in mobile devices such as smartphones or tablet computers, as well as in stationary systems like ticket vending machines or information terminals. Using touch screens, it is possible to perform complex interactions in a small area while remaining flexible in layout and adaptive to the task at low cost. Compared to mechanical keyboards, sliders, and buttons, these interactive devices mimicked on touch

screens show the disadvantage, that tactile feedback and familiar feeling transmitted via the sense of touch, as provided by mechanical components, is lost. Typing on a touch screen is more difficult and results in a lower input speed and higher error rates (Hoggan et al. 2008). To address this problem, artificially generated vibrations provide tactile feedback in today's smart devices. In addition to that, using the tactile sense to convey information is a promising approach to improve human-machine interaction (Spence 2015, El Saddik 2007), in particular when the visual or auditory channel is overloaded or not available (Brewster and Brown 2004a), and this is of both empirical and commercial interest (Ho et al. 2005). The term "tactile" describes the information conveyed by the mechanoreceptors in the skin, while the term "haptic" includes additional information provided by the proprioceptive system.

The elements for transmitting more complex information via the tactile sense have been named *tactons* (Brewster & Brown 2004a, 2004b). Tactons are structured tactile messages using modulation of parameters like frequency, amplitude, duration, etc. for information transmission to the user. Compared to simple vibrations, the design of tactons is flexible, and depends on the information they encode.

## 1.1 Related Work

Several studies in the last 20 years examined information transfer via the tactile sense, taking into account several parts of the human body, beyond touch screens and finger tips.

For example, tactile feedback was successfully used to present directional cues on participant's torso (van Erp et al. 2005, van Erp 2005, Tan et al. 2003) or to increase situational awareness (Tan et al. 2003, Sklar and Sarter 1999), also in altered gravity environment (Traylor and Tan 2002, Rochlis and Newman 2000). However, in these studies, tactile feedback was rather simple, comprising mostly of a constant vibration at a fixed frequency of 250 to 300 Hz. Other researchers showed that tactile feedback could help to estimate distance-to-obstacle in the absence of vision (Hartcher-O'Brien et al. 2015) and even can be used to improve the level of surgical precision during laser surgery procedures (Fichera et al. 2016). Domhardt et al. (2013) found that tactile feedback can reduce driver distraction and improve efficiency of working on an additional secondary task while driving (operating a touchpad with/without tactile feedback) in a driving scenario.

A large amount of demand for tactile feedback and, consequently, for research arose with the advent of touch screens used for text and command input in stationary and even more in smart mobile devices.

While interacting on a flat steady surface like a touch screen or a flat virtual or real keyboard, tactile feedback can improve typing speed and reduce error rate, especially when tactile feedback is provided rather local than global (Ma et al. 2015, Kim and Tan 2014), and facilitate typing performance (Sim et al. 2016). Similar results can be found for mobile applications (Yatani and Truong 2009, Hoggan et al. 2008). In an eyes-free setup, lower error rate was achieved when the tactile feedback was given in a precise way matching participants' contact point on the touch screen (Yatani and Truong 2009). Research and resulting design recommendations exist concerning a simple touch screen interaction like a button click, e.g. about providing a tactile "click" feeling when users touch the virtual buttons on a touch screen (Fukumoto and Sugimura 2001) and artificially created button edges on a touch screen (Pakkanen et al. 2010, Nashel and Razzaque 2003). Moreover, the most pleasant tactile feedback for mobile (Koskinen et al. 2008) and stationary (Stein et al. 2016) touch-sensitive

screens were already examined. In the latter experiment, different frequency and amplitude levels were presented to the participants who could choose their preferred, most pleasant, combination of these two parameters. Concerning frequency, it was found that a perceived higher intensity was rated by the participants as less comfortable and vice versa. The subjectively most pleasant amplitude depended on participants' sex and age (Stein et al. 2016), a dependency easily explained by skin sensitivity.

Although just feeling the click when a button moves is important for fast and reliable interaction, the human tactile sense is capable of receiving more information, when simple button clicks are replaced by meaningful tactons.

The application areas of tactons are diverse. First, tactons can be presented via different devices to different parts of the user's body: By a computer mouse (Chan et al. 2008, Klatzky and Lederman 2006), or a "PHANTOM" that is a high performance, 3D haptic interface (SensAble Technologies) (Lederman et al. 2006, Sjöström 2001) to the hand, by waist belts (van Erp et al. 2005) or via torso displays (van Erp 2005, Tan et al. 2003), by a vibrotactile wristband (Arab et al. 2015), and from touch screen surface to the fingertip.

Second, tactons can convey any – unless not too complex – information. As an example, tactons presented progress information during file download while the user worked on other tasks (Brewster and King 2005). Therefore, three different tactons, all with the same frequency of 250 Hz but different durations and rhythms, informed the user about the status of the current download (i. e., start of a new download, current progress, and end). The time to respond to the end of a download was measured in a standard visual condition and a tactile condition (without visual display of progress) and showed a significant improvement of performance in the tactile condition. Moreover, an overall preference for the tactile display was found (Brewster and King 2005).

In another study, tactons were used to inform the user about type and priority of an incoming message (Brown et al. 2005). Message type (voice call, text message, multimedia message) was encoded by rhythm, and priority (low, medium, high) by the roughness of the vibration. The sensation of roughness is created by multiplying a sine wave of a given frequency by a sine wave of another frequency, thus modulating the amplitude of the base signal by the second frequency (Brown et al. 2005). Here, a 250 Hz sine wave was used without modulation and modulated by a 50 Hz and a 30 Hz sine wave, respectively, to yield three different roughness levels. Results showed that type of message (encoded by rhythm) was recognized on average 93 % and the priority (roughness) showed an average recognition rate of 80 % (Brown et al. 2005).

In a similar experiment, the encoded information was increased to three dimensions represented by a tacton (Brown et al. 2006). Type of, importance of, and time until an upcoming appointment (each with three different levels) were encoded by rhythm, roughness and spatial location, respectively. While rhythm and roughness were the same characteristics as in the latter experiment, time was encoded by the location of three tactors, which were attached at the wrist of the participant, the elbow and a point equidistant between them. Results showed a recognition rate of 96.7% for appointment type (represented by rhythm), 50.2 % for importance (roughness) and 95.5% for remaining time (location). To improve the recognition of roughness, the experiment was repeated with only two different levels of roughness, while rhythm and spatial location were kept. Appointment types (99.1%) and remaining time (98.8%) showed no significant differences compared to the primary experiment, but roughness recognition rate improved significantly (82.4%) (Brown et al. 2006).

To examine the use of tactons to provide ambient information on a mobile device, e.g. while the user is typing a message, another set of tactons was designed (Constantin and Brewster 2010). Tactons encoded proximity events of two different groups of persons (friend or child, represented by the two different levels of roughness used in the latter experiment) and three current locations (far, close, and in office/school, represented by rhythm using a one-note, two-note and four-note vibration, respectively). This setting was challenging because tactons need to be short (300 ms duration) but still distinguishable. Results showed an overall recognition rate of 87.7 %. Reducing the number of events to be recognized during the experiment led to an improved recognition rate of 98.3 % (Constantin and Brewster 2010).

To summarize these findings of previous studies, rhythm and roughness seem to be suitable parameters to transmit information via the tactile sense even when signal duration is very short. In each of these studies, the tacton was placed on a non-interacting part of the participants, a finger, hand or forearm. However, in future applications, e. g. when tactons are used in touch screen interaction, the device itself the user is interacting with will probably generate the tactile feedback providing it to the user's interacting finger. In this case, it is important to investigate whether existing empirical findings are transferable to situations where a user is interacting with flat surfaces like a touch screen.

## **1.2 Aim of the Study**

Thus, it is reasonable to examine all possible parameters for encoding information via tactile feedback in such a scenario to generate valid design recommendations based on findings with a large number of participants.

The aim of the study described below is to examine the given parameters for a touch screen interaction scenario. For the described scenario, location as well as spatiotemporal pattern are unsuitable parameters because there is only one location to provide tactile feedback, namely the user's interacting finger. In this regard, the parameters frequency, amplitude, rhythm, roughness, waveform, and duration of tactile feedback were examined. The results of this experiment will help to derive distinguishable levels of parameters for tacton design.

## **2. METHOD**

### **2.1 Experimental Setup**

A stationary touch screen mock-up was built up using aluminum profiles (Figure 1). A 15-inch LC-display, adjustable in height and tilt angle, was attached. A 19-inch surface capacitive touch screen panel (3M ClearTek II with an USB-Controller 3M EXII-7760UC) was installed above the display, supported by four single piezoelectric actuators (PI Ceramic's P-820.3B), each mounted with a preload force applied through a spring, in the screen corners (Figure 2). These actuators were controlled by a multifunction data acquisition device (National Instruments' USB-6002) and powered by four power amplifiers (PI Ceramic's E-617.00F) providing synchronous tactile feedback across the whole screen. An optical laser displacement sensor (Keyence LK-32) was installed below the touch screen to measure the surface

movement of the panel. A measuring system BioPac MP 150 recorded data of the displacement sensor with a sampling frequency of 1000 Hz.

Moreover, two cameras, one at the right edge of the touchscreen (Figure 2) and one at the upper aluminum profile of the mock-up (not shown), were attached to observe participants' hand and finger movements.



Figure 1. Stationary touch screen mock-up used in this experiment

The place of the researcher on the opposite consists of a common computer with keyboard, mouse and monitor where the software for the study is played. This experiment was programmed using National Instrument's LabVIEW software.

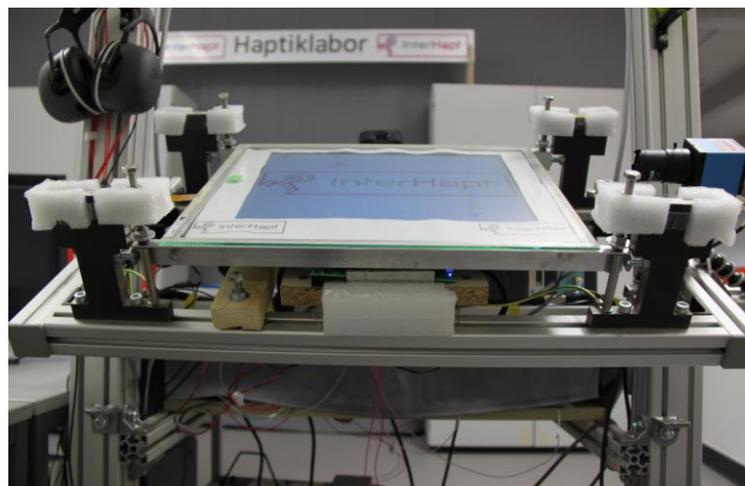


Figure 2. Technological components of the touch screen mock-up

## 2.2 Tactile Feedback Parameters

While only one parameter was altered in a single comparison, the other parameters were set to standard values. Table 1 lists all parameters of the tactile feedback and their values examined in this study as well as the values used for the standard signal. Each value of one parameter was compared with all the other values of the same parameter (except “continuous” rhythm, and “not applied” roughness which were only used in the standard signal). Example: Six different frequency levels ( $L_{freq}$ ) led to

$$N_{freq} = L_{freq} \cdot (L_{freq} - 1) / 2 = 15$$

paired comparisons of the parameter frequency. A total of 87 different paired comparisons were presented. In addition to that, 11 control pair signals were added comprising identical vibrations while ensuring that an identical comparison of each parameter was involved. Hence, the experiment consisted of 98 tasks which were presented once to the participants in a randomized way. The following list explains parameters used and values taken.

Table 1. Parameters and values examined in this study

Frequency (N = 15)	Amplitude (N = 21)	Rhythm (N = 15)	Roughness (N = 15)	Waveform (N = 6)	Duration (N = 15)
120 Hz					
144 Hz	8.0 $\mu\text{m}$				
173 Hz	10.0 $\mu\text{m}$				450 ms
208 Hz	12.5 $\mu\text{m}$				475 ms
250 Hz	15.0 $\mu\text{m}$	continuous	not applied	sine	500 ms
290 Hz	18.0 $\mu\text{m}$	short short	50 Hz / 6 Hz	triangle	525 ms
	22.0 $\mu\text{m}$	short short short	50 Hz / 10 Hz	square	550 ms
	26.5 $\mu\text{m}$	short short long	100 Hz / 12 Hz	sawtooth	600 ms
		short long short	100 Hz / 20 Hz		
		short long long	250 Hz / 30 Hz		
		long long	250 Hz / 50 Hz		
					standard signal

**Frequency.** The fingertip is most sensitive for vibration at frequencies close to 250 Hz (e. g. Gescheider et al. 2004, Verrillo and Gescheider 1992). In recent experiments with tactile feedback on flat surfaces, authors identified a preferred frequency of 150 Hz and frequencies of 100 Hz, 200 Hz and 250 Hz to be pleasant as well (Stein et al. 2016). Therefore, frequencies between 100 Hz and 300 Hz were examined to cover this range. Differences between the frequencies were determined to be at least 20 % (van Erp 2002). The standard signal was set to 250 Hz satisfying the maximum fingertip sensitivity criterion. Because of technical restriction – the actuators were not able to generate an accurate 300 Hz vibration at an amplitude of 15  $\mu\text{m}$  (required for the standard signal) – the upper frequency was set to 290 Hz.

**Amplitude.** Values of the amplitude were all set in the perceptible and pleasant (Stein et al. 2016) spectrum which was examined interacting on a flat steady surface and thus, under conditions comparable to a touch screen interaction scenario. The differences between the single amplitudes were derived from the suggestion of Pongrac (2008).

**Rhythm.** To design different rhythms, a short (50 ms) and a long (150 ms) vibration were combined in various combinations using two or three single impulses. Derived from van Erp’s indication (2002), a pause of 50 ms was set between the different impulses. Example: “short

long short” in Table 1 stands for “short impulse (50 ms) – pause (50 ms) – long impulse (150 ms) – pause (50 ms) – short impulse (50 ms)”.

**Roughness.** In several experiments of Brewster’s Human-Computer Interaction Group (Brown et al. 2006, Brown et al. 2005) a 250 Hz sine wave, modulated by a 50 Hz as well as a 30 Hz sine wave was determined as suitable for tacton design. To investigate whether signals with other frequencies but the same ratio between base signal and second signal are distinguishable, too, the frequencies 100 Hz and 50 Hz were chosen and modulated by a signal with 20 % and 12 % of its value.

**Waveform.** On the one hand, some recent work states that waveform seems not to be a suitable parameter for tacton design (Constantin and Brewster 2010, Brewster and Brown 2004a, Brewster and Brown 2004b) and that a sine, triangle, and sine<sup>2</sup> stimulus are considered to feel little different, as well as a square and a sawtooth stimulus (Merchel and Altinsoy 2009). On the other hand, waveform was found to deliver recognition rates about 94 % when comparing sine, square and sawtooth wave (Hoggan and Brewster 2007). Therefore, sine, triangle, square, and sawtooth waves were tested in this study to examine which suggestion is valid for the application scenario regarding a touch screen interaction.

**Duration.** Duration is an important parameter in tacton design because signals need to be long enough that the user can receive the encoded information but not too long making information transfer slow. The duration of a single touch screen input in consideration of various influencing factors, i. e., participants’ position (standing or sitting), inclination of the display, and button size, is already known and amounts to 169 ms on average (Seeger et al. 2015). However, for complex information transmitted via tactons, duration presumably needs to be longer. Several durations ranging from 450 ms to 600 ms were used and their comparisons led to differences between 25 ms and 150 ms.

## 2.3 Participants

51 (22 female, 29 male) participants took part in this study. Their mean age was 30 years ( $\pm 9$  years, range 21 – 64 years) and 48 of them (94 %) used the right hand for writing, though carried out the experiment with their right hand, 3 participants (6 %) used their left hand.

## 2.4 Experimental Procedure

The setting of the experiment was rather simple. Basically, participants were presented two vibration signals on the index finger of their dominant hand via a touch screen and had to decide, whether signals were identical or different. The overall time required by one participant to complete the 98 tasks comprising 87 different and 11 identical paired comparisons was 25 to 30 minutes. Before the start of the experiment, participants got a short introduction and signed the experimental agreement. They were indicated to work as accurate as possible regardless of the time required to make their decision, motivated by an incentive for the best three results (15 €, 10 €, and 5 €). After a short test run to become familiar with the setting and the user interface, participants started the experiment. By touching the two test buttons A and B (see Figure 3), the first two different tactile feedback signals were presented to the participants who had to decide whether the signals were identical or different. When both test buttons were touched at least once, two answer buttons in the middle (“identical”, upper button colored green, and “different”, lower button colored red; Figure 3) appeared.

After this decision, the next paired comparison appeared and the answer buttons disappeared until test buttons A and B were activated once again and so on. Participants were allowed to replay the two signals as often as they liked before making their decision.

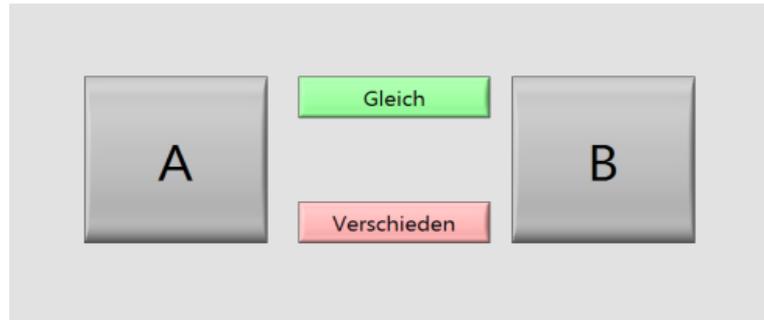


Figure 3. User Interface of the experiment

During the experiment, they had to wear in-ear headphones playing white noise and additional hearing protectors to avoid acoustical inducements caused by the noise generated by the piezoelectric actuators.

### 3. RESULTS

#### 3.1 Recognition Rates

The overall recognition rate was  $0.69 \pm 0.15$ . In Table 2, the recognition rates and the standard deviations of the parameters examined are summarized. A t-test found a significant difference when comparing the recognition rates of the identical signals and the different signals ( $p < 0.001$ ,  $df = 50$ ), indicating that identical signals were correctly identified more frequently. T-tests showed that there were no significant differences in the results of men and women ( $p = 0.931$ ,  $df = 49$ ) as well as in the results of younger and older participants ( $p = 0.871$ ,  $df = 23$ ) comparing the lower and upper quartile (see also Stein et al. 2017).

Table 2. Recognition rates and standard deviations of the parameters

	Frequency	Amplitude	Rhythm	Roughness	Waveform	Duration	Identical signals
<b>Recognition rate</b>	0.89	0.65	0.79	0.90	0.40	0.27	0.83
<b>Standard deviation</b>	0.11	0.24	0.16	0.18	0.12	0.07	0.07

Comparing the single recognition rates of the parameters is not practical because some paired comparisons within one parameter are more suited than others so that an overall comparability of the single parameters seems not to be feasible.

### 3.2 Stimulus Pairs Identified as Suitable

Table 3 lists all paired comparisons participants were able to discriminate in at least 90 % of the cases. Recognition rates above 90 % are seen as “close to perfect” (Brown et al. 2006, p. 234) and therefore defined as the threshold for suitable combinations. All other pairs failed in reaching this threshold. In Table 3, only the discriminating parameters and its values are listed, other parameters were set to standard signal (see Table 1).

Table 3. Suitable paired comparisons with recognition rates  $\geq 90\%$

	Paired comparison	Recognition rate
Frequency	120 Hz / 144 Hz	0.90
	120 Hz / 208 Hz	1.00
	120 Hz / 250 Hz	0.92
	120 Hz / 290 Hz	1.00
	144 Hz / 250 Hz	0.92
	144 Hz / 290 Hz	0.98
	173 Hz / 250 Hz	0.94
	173 Hz / 290 Hz	0.90
	208 Hz / 250 Hz	0.92
	250 Hz / 290 Hz	0.96
Amplitude	8.0 $\mu\text{m}$ / 18.0 $\mu\text{m}$	0.92
	8.0 $\mu\text{m}$ / 22.0 $\mu\text{m}$	0.94
	8.0 $\mu\text{m}$ / 26.5 $\mu\text{m}$	0.96
	10.0 $\mu\text{m}$ / 26.5 $\mu\text{m}$	0.90
	12.5 $\mu\text{m}$ / 26.5 $\mu\text{m}$	0.94
Rhythm	short short short / short long long	0.92
	short short long / short short	0.98
	short long short / short short	0.98
	short long long / short short	0.98
	short long long / long long	0.92
	short short / long long	0.96
Roughness	250 Hz, 50 Hz / 100 Hz, 20 Hz	0.98
	250 Hz, 50 Hz / 100 Hz, 12 Hz	0.98
	250 Hz, 50 Hz / 50 Hz, 10 Hz	1.00
	250 Hz, 50 Hz / 50 Hz, 6 Hz	1.00
	250 Hz, 30 Hz / 100 Hz, 20 Hz	1.00
	250 Hz, 30 Hz / 100 Hz, 12 Hz	1.00
	250 Hz, 30 Hz / 50 Hz, 10 Hz	1.00
	250 Hz, 30 Hz / 50 Hz, 6 Hz	1.00
	100 Hz, 20 Hz / 50 Hz, 10 Hz	0.96
	100 Hz, 20 Hz / 50 Hz, 6 Hz	1.00
	100 Hz, 12 Hz / 50 Hz, 10 Hz	0.94
	100 Hz, 12 Hz / 50 Hz, 6 Hz	0.96

In this experiment, nine paired comparisons were correctly distinguished by all 54 participants (recognition rate = 1.00), namely two comparisons of the parameter frequency and seven comparisons of the parameter roughness (see also Stein et al. 2017).

### 3.3 Ratios of Frequency and Amplitude

To derive design recommendations, it is interesting to find out what makes different values of one parameter distinguishable. For frequency and amplitude, this leads to compare ratios. Figure 4 and Figure 5 show the recognition rates against the ratio of the two compared frequencies and amplitudes, respectively. For example, the paired comparison of frequencies 144 Hz and 290 Hz results in a ratio of 2.01 and was correctly distinguished by 98 % of the participants in this experiment. It is obvious, that an increasing ratio leads to higher recognition rates for frequency as well as for amplitude. Regarding duration, a similar effect cannot be detected (see also Stein et al. 2017).

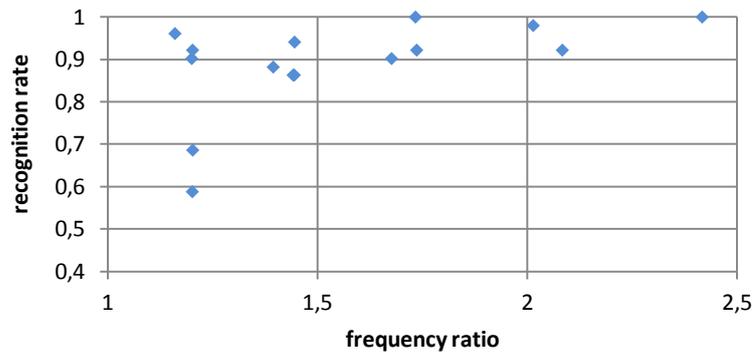


Figure 4. Recognition rate against frequency ratio

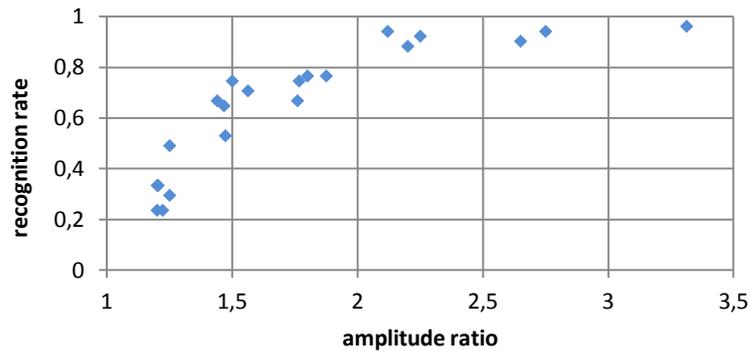


Figure 5. Recognition rate against amplitude ratio

### 3.4 Results of Parameter Rhythm

Concerning parameter rhythm, the overall recognition rate is 0.79 while six paired comparisons reached the 90 % threshold. Given that rhythm is a complex parameter, a closer look on the single paired comparisons could be interesting. Table 4 lists all paired comparisons of the parameter rhythm as well as their durations, the duration difference and the resulting ratio, their recognition rate and category. Four categories were defined:

- A = same number of single impulses and duration difference  $\leq 100$  ms
- B = different number of single impulses and duration differences  $\leq 100$  ms
- C = same number of single impulses and duration differences  $\geq 200$  ms
- D = different number of single impulses and duration differences  $\geq 200$  ms

Table 4. Paired comparisons of parameter rhythm

Paired comparison	Duration signal A [ms]	Duration signal B [ms]	Duration difference [ms]	Ratio	Recognition rate	Category
short short long / short long short	350	350	0	1.00	0.55	A
short long short / short long long	350	450	100	1.29	0.59	A
short short short / short short long	250	350	100	1.40	0.59	A
short short long / short long long	350	450	100	1.29	0.61	A
short short short / short long short	250	350	100	1.40	0.63	A
short short long / long long	350	350	0	1.00	0.73	B
short long short / long long	350	350	0	1.00	0.75	B
short short short / long long	250	350	100	1.40	0.84	B
short short short / short short	250	150	100	1.67	0.84	B
short long long / long long	450	350	100	1.29	0.92	B
short short short / short long long	250	450	200	1.80	0.92	C
short short / long long	150	350	200	2.33	0.96	C
short long short / short short	350	150	200	2.33	0.98	D
short short long / short short	350	150	200	2.33	0.98	D
short long long / short short	450	150	300	3.00	0.98	D

It can be seen that recognition rates increase between the defined categories A – D while each recognition rate of categories C and D – and one of category B – reaches the 90 % threshold (Brown et al. 2006). A chi-square test with two variables (*category A – D* and *answer correct/incorrect*) was performed showing that there is a significant association between the type of category and the achieved recognition rate  $\chi^2(3) = 108.981$ ,  $p \leq 0.001$ . Two 2 x 2 contingency table tests examine the effect of *number of single impulses* and *duration difference* separately. The relation between *same/different number of single impulses* and *correct answer* ( $\chi^2(1) = 39.641$ ,  $p \leq 0.001$ ) as well as between *shorter/longer duration differences* and *correct answer* ( $\chi^2(1) = 69.897$ ,  $p \leq 0.001$ ) is significant with effect sizes of 3.18 and 11.48, respectively.

## 4. DISCUSSION

### 4.1 Caveats: Interaction and Identification

It is necessary to mention, that altering one parameter of a vibration signal could influence the perception of other parameters. For example, a change in amplitude leads to a change in the perception of frequency, which has an impact on the use of frequency as a cue (Brewster and Brown 2004b). Ishihara et al. (2014) found that various types of waveforms (i. e., triangle wave, square wave, and sine wave) led to different perceptions of surface roughness. As described in 3.4, the various rhythms used in this experiment were also different in their length of time (i. e., 150 ms – 450 ms), thus interact with duration. Therefore, even if only one parameter of a vibration signal is altered, one has to be aware that there could be an effect on other parameters, too, which can also influence recognition rates.

Making relative comparisons between stimuli is much easier than absolute identification (Brewster and Brown 2004a). In this study, the different parameter levels were discriminated in a relative way, which means that participants always had the possibility to compare two signals before making their decision. In future tacton design, it will be important to generate tactons that can be identified clearly without any comparison. Some considerations to solve this problem are presented in 4.3.

### 4.2 Design Recommendations

To generate sets of discriminable tactons for different application areas, the following recommendations could be given:

**Frequency.** For the parameter frequency, the ratio should be at least 1.5 (see Figure 4). Using this threshold, participants in this experiment were able to discriminate the presented signals in more than 90 % regardless of the frequency values used. Furthermore, it is known that no more than nine different levels of frequency should be used for coding information (van Erp 2002).

**Amplitude.** Only four of the 21 combinations of amplitude were discriminated correctly by more than 90 %. As shown in Figure 5, a ratio of 2.5 can clearly be discriminated by more than 90 % and should therefore be chosen for tacton design when using amplitude as a parameter. In addition to that, no more than four levels should be used when encoding information by amplitude (van Erp 2002). Another suggestion is to leave amplitude under the control of the user (Brown et al. 2005, Pakkanen 2010) because of their different perception thresholds, individual preferences and possible impairment of other parameters' perception. But in particular, when coding different safety levels, e. g. the state of a process of an industrial system, different levels of amplitude should be used to indicate danger, warning or safety (VDI/VDE 3850-1).

**Rhythm.** Concerning rhythm, the rather similar signals were deliberately chosen to find out if even these similar rhythms are distinguishable. Based on the findings of this experiment, rhythm seems to be a suitable parameter for the examined scenario. In a former study, Summers (2000) figured out that participants used temporal pattern information rather than information from frequency/amplitude modulation for decoding speech information from vibration signals indicating that rhythm could be a dominant parameter for tacton design. Of course, more than only two impulses with different durations – i. e., “short” (50 ms) and

“long” (150 ms) (see 2.2) – could be used and combined. As shown in 3.4, best results can be achieved when number of single impulses differs between various rhythms and duration difference is more than 200 ms. To sum up, rhythm enables a multiplicity of possible signals and opens a wide range for tacton designs.

**Roughness.** Roughness was already supposed to be a suitable parameter, which can be confirmed. However, only when the base signals of the paired comparison had different frequencies, the recognition rate was adequate. This contrasts to former findings where two signals using the same base signal and merely other second signals for roughness creation led to acceptable recognition rates, too (Brown et al. 2006, Brown et al. 2005). Physiological (e. g. location and size of the contact area where the tacton is applied) as well as technological aspects (e. g. technology used for tacton generation) may explain this difference, which cannot finally be answered. Nevertheless, roughness can be used to encode information and, moreover, other base signals besides 250 Hz can be chosen, which makes tacton design using roughness more diversely.

**Waveform.** In a touch screen interaction scenario, waveform seems to be an inappropriate parameter for encoding information and should therefore not be used in tacton design. The best recognition rate occurred by comparing a sine and a sawtooth wave (54.9 %), but the result is still far from being a suitable combination according the defined threshold of 90 %.

**Duration.** Duration has to be more diverse than the values applied in this experiment when using it to encode information. None of the paired comparisons of the parameter duration achieved a suitable recognition rate. Nevertheless, choosing more diverging values, duration could still be a suitable parameter in tacton design. Results in 3.4 support this assumption, thus, examining the parameter duration with more diverging values in future studies could clarify its suitability.

### 4.3 Future Tacton Design

Tactons are abstract, so the mapping between the tacton and what it represents must be learned by the users (Brewster and Brown 2004a). A promising approach for this problem is proposed by Chan et al. (2008, 2005). They designed tactons for a turn-taking protocol in remote collaboration and defined three different tacton families (i. e., changes in control, being in control, waiting for control). The tactons were presented to the users via their computer mouses. The design of the tactons is based on metaphors, e. g. waiting for control is coded as a pulse sensation to the users suggesting a person tapping or drumming her fingers while waiting (Chan et al. 2005). Using such metaphors should make the tactons intuitive to learn and help users to understand and memorize the particular meaning of the tactons more easily. This suggestion reaches its limits when the number of tactons increases and one metaphor could stand for different functions.

A possible solution to address this problem could be to design groups of general valid tactons, e. g. rough, unpleasant vibration signals which encode functions that are connoted negatively (like wrong input, interruption of operation, etc.) and smooth, comfortable tactons for functions with positive associations (like entry confirmed, process completed, etc.).

Another approach could be to define a set of tactons for recurrent functions in computer application menus (e. g. OK, delete, up or down). This standard set of tactons could be extended with other tactons while the subfunctions are encoded by a similar tacton like their superior standard function, thus, remaining in the same tacton family.

## 5. CONCLUSION AND FUTURE WORK

In this research, regarding an input on a flat surface, common parameters for encoding information were examined. Suitable values and distinguishable levels for single parameters became clearer and design recommendations were derived. Based on the experimental findings, a variety of possible applications could be examined, and tactons for many different applications and devices can be designed.

Furthermore, by comparing the results of this experiment with former research, it becomes clear that findings cannot simply be transferred to other application scenarios but should rather be tested under the particular conditions.

It will also be interesting to find out how the findings of this study can be translated for a user-held device like a smartphone or a tablet and if the signals received in the other hand impact perception on the interacting finger.

In future tacton design for touch screen applications, using the parameters and thresholds proposed in this study, it is also desirable to find appropriate metaphors for the encoded function to help users understand the tactons and make them easier to learn.

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