New Parameters for Tacton Design

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Abstract
Tactons (tactile icons) are structured vibrotactile messages which can be used for non-visual information presentation. Information can be encoded in a set of Tactons by manipulating parameters available in the tactile domain. One limitation is the number of available usable parameters and research is ongoing to find further effective ones. This paper reports an experiment investigating different techniques (amplitude modulation, frequency, and waveform) for creating texture as a parameter for use in Tacton design. The results of this experiment show recognition rates of 94% for waveform, 81% for frequency, and 61% for amplitude modulation, indicating that a more effective way to create Tactons using the texture parameter is to employ different waveforms to represent roughness. These results will aid designers in creating more effective and usable Tactons.

Keywords
Tactile icons, Tactons, non-visual interaction

ACM Classification Keywords
H5.2. User Interfaces: Haptic I/O.

Introduction
Tactons are structured vibrotactile messages which can be used to communicate information non-visually [2]. They are the tactile equivalent of audio Earcons [1] and

visual icons, and can be used for communication in situations where vision is overloaded, restricted, or unavailable.

Tactons have been designed to improve interaction in applications where visual displays are limited. For example, mobile devices handle ever increasing amounts of information but can have problems displaying it due to their reliance on small visual displays. Tactons allow information from these devices to be accessible in an effective and safe way to users on the move. Like mobile users, people with visual disabilities may not be able to use information presented graphically but, by using Tactons, they are able to access the same information in a more useful form. Most recently, crossmodal Tactons and Earcons have been created so that mobile devices can translate information into an auditory or tactile form so that it can be presented to users in the most appropriate modality [4].

When creating a set of Tactons the first step is to identify the parameters of vibration that can be used to encode information. The set of parameters that can be manipulated is smaller than in sound for example, and this reduces the number of stimuli that can be created. Researchers are trying to find effective new parameters that can be used for encoding. Previous studies have investigated parameters for Tacton design such as rhythm, spatial location and vibrotactile roughness. Brown *et al.* [3] have conducted experiments which have shown recognition rates of over 95% for both rhythm and spatial location, indicating that Tactons could be a successful means of communication. However, the individual results for tactile roughness (created using amplitude modulation) show a recognition rate of just 57.2%, suggesting that such a design is not effective and an alternative is needed.

The study presented here investigates different representations of tactile texture for use in Tacton design to see how the recognition rates of these new parameters compare to those achieved by roughness.

Stimuli

Amplitude Modulation

Tactile roughness as used before in Tacton design [3] is created by using amplitude modulated sinusoids. These are created by multiplying a sine wave of a given frequency by a sine wave of another frequency. The roughness levels used previously [3] and also in this experiment were: an unmodulated 250Hz sine wave (smooth), the same sine wave modulated by 50Hz (rough), and by 30Hz (very rough), see Figure 1.

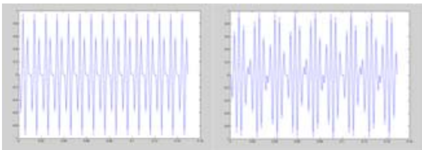

figure 1: 250Hz sine wave modulated by 50 Hz sine wave and 30Hz sine wave [3].

Frequency

There are conflicting views as to whether using different frequencies to create different textures is an appropriate parameter for Tactons. On the one hand, because the frequency range of the skin is only from 10Hz to 400Hz, and the usable frequency range is further reduced by the limited bandwidth of standard actuators, frequency is unsuitable as a parameter in Tacton design [2]. However, on the other, studies have shown that frequency can still play a role in tactile texture as subjects in psychophysical experiments have reported a sensation of periodicity or buzzing at low frequencies (below 100Hz) while at higher frequencies a more diffuse, smooth sensation is perceived [8]. Furthermore, different frequencies have been used in experiments with multifinger tactual displays [7] where it was shown that participants could categorise frequencies into three perceptually distinct groups over the range of DC to 300Hz. Therefore, in the study presented here, the frequency levels used were based on the results from the multifinger tactual display experiments. The levels used were: 6 Hz (slow motion, very rough), 70Hz (fluttering slightly faster motion, rough), and 250 Hz (smooth) as shown in Figure 2.

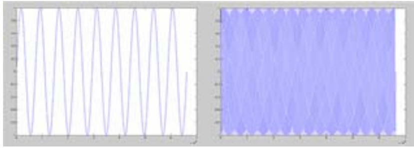

figure 2: 6Hz sine wave and 70Hz sine wave.

Waveform
Like frequency, there are also conflicting views as to whether using different waveforms to create different textures is an appropriate technique for Tacton design. Originally it was decided that, although users can differentiate between sine waves and square waves, the number of different values that could be encoded in would be limited [2]. However, it has been shown by Miller [5] that it is better to have a small number of values for several attributes of a stimulus set as opposed to having many values for one attribute of the stimuli. Furthermore, the vibrotactile range from pure sine tone to noise is often described as a continuous transition from smoothness to roughness [6]. So, in Tacton parameter design, waveform can be correlated to the 'texture' of tactile stimuli. Also, waveform (timbre) is a key attribute in Earcon design [1] and, if Tactons are to be used in crossmodal applications with Earcons [4], it would seem to be an important parameter to investigate.

Initial pilot studies with 6 participants showed they could distinguish between a sine wave (very fast, smooth), and sawtooth wave (fast, rough), and a square wave (slow, very rough). Therefore, in this experiment a sine wave, square wave and sawtooth wave were used. The square waves were created using the Fourier series made up of the sum of odd harmonics of sine waves. When adding harmonics, it was ensured that the amplitude levels created by each harmonic were always within the 250Hz resonating frequency of the actuator.

Vibrotactile Hardware
The set of Tactons developed in this study were presented to users through a C2 Tactor (figure 4) from Engineering Acoustics Inc (www.eaiinfo.com). This device is a voice coil transducer with a contact point located outside of the case so that the user feels the vibration through the contact point. The C2 Tactor was attached to the index finger of the non-dominant hand.

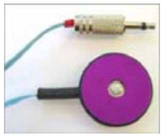

figure 3: Engineering Acoustics Inc (EAI) C2 vibrotactile actuator.

The Experiment

The aim of this experiment was to investigate alternative representations of tactile textures (based on frequency and waveform) for use in Tacton design and to examine the recognition rates of these new parameters in comparison with those achieved by tactile roughness (amplitude modulation). The hypotheses were:

1. There will be a difference in participants' ability to recognize three different levels of texture in cues using amplitude modulation, frequency, or waveform.

2. Participants will be able to distinguish between the three different textures created by the three different waveforms and three different frequency levels (over 90% correct identification)

Methodology

Nine people took part in the experiment, aged between 20 – 36 years, 4 female and 5 male, all members of staff or students at the University of Glasgow. The experimental method used was a within-groups design where each participant was tested on all three conditions – amplitude modulation, frequency, and waveform in a counterbalanced order.

There were 54 tasks in this experiment, 3 different rhythms (see figure 4) were used with each of the three conditions – amplitude modulation (rhythms 1, 2, and 3 made up of a 250Hz unmodulated sine wave, a 250Hz sine wave modulated at 50Hz, and one modulated at 30Hz each repeated twice), frequency (rhythms 1, 2, and 3 made up of a 250Hz sine wave, a 70Hz sine wave, and a 6Hz sine wave each repeated twice), and waveform (rhythms 1, 2, and 3 made up of a sine, square, and sawtooth wave each repeated twice).

The Tactons used each lasted approximately 1 second and rhythms contained at least one minim (a longer pulse of 500ms in this case).

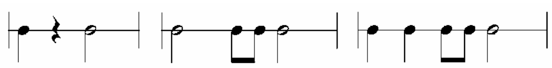

figure 4: Rhythm 1, 2 and 3 used in the experiment.

The Tactons represented cues which might occur on a mobile phone to inform the user of the urgency of incoming alerts. The urgency of the alerts was encoded in the texture with the three different levels of texture (very rough, rough and smooth) created by amplitude modulation, frequency or waveform mapped to the urgency of the alert (very urgent, urgent or not urgent). In each task participants were presented with a Tacton and asked to identify the corresponding alert. The stimulus was presented four times and the participant could respond at any time by selecting the corresponding button in the experimental software (figure 5).

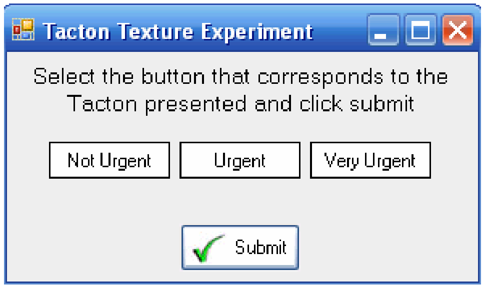

figure 5: Screenshot of experiment interface

Before beginning the experiment participants were presented with a tutorial to introduce them to the concept of Tactons, texture, rhythm etc. They were then allowed to familiarize themselves with each of the different types of Tactons for ten minutes before beginning the actual tasks.

Results

During the experiment, the experimental software recorded data on the participants' responses to each stimulus. From these results percentage correct scores were calculated for each stimulus (figure 6).

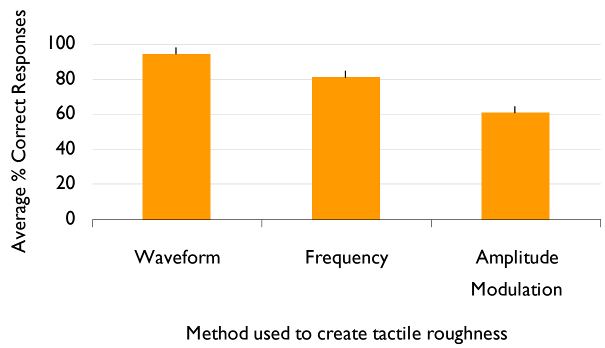

figure 6: Average Percentage Correct Scores for each tactile roughness technique.

The average recognition rates for waveform were 94.2% with 81% for frequency, whereas the average recognition rates for amplitude modulation were only 61.1% (similar to that found by Brown [3]) therefore hypothesis 2 can be partially accepted as recognition rates for waveform are over 90% but not for frequency. Participants were interviewed after taking part in the experiment and several of them indicated that they found frequency quite difficult as the cues were not long enough to allow them to distinguish the different frequencies. This would suggest that rhythms with longer notes may improve results for the identification of tactile texture using frequency. To improve results for frequency, a longer rhythm could be created lasting 2 seconds or, each rhythm could include at least one semibreve (a long pulse of 1 second in this case).

To test hypothesis 1, first the significance of the effects of each representation of tactile texture was investigated. The statistical analysis used is a standard two-tailed one factor ANOVA analysis, based on the critical values of the F distribution, with alpha=0.05. The ANOVA shows there are significant differences in the error data between tactile texture conditions ($F=58.14 > F(2, 51) = 5.2$). Tukey's pairwise HSD analysis showed that the average number of errors for amplitude modulation was significantly greater than the number of errors in frequency and waveform. The analysis also showed that the average number of errors for frequency was significantly greater than the number of errors in waveform. Overall, hypothesis 1 can be accepted.

Overall, the recognition rates of Tactons using amplitude modulation are slightly higher than in previous experiments [3] but still produce poor results compared to waveform and frequency. The results of this experiment indicate that using different waveforms to represent tactile texture as a parameter in Tactons would be more effective than using amplitude modulation.

Conclusions and Future Work

This study investigated perception of tactile texture with a view to identifying the best technique (amplitude modulation, differing waveforms, or differing frequencies) to use when including texture as a parameter in the design of Tactons. The results, with recognition rates of 94.2% for differing waveforms, 81% for differing frequencies, and 61.1% for amplitude modulation indicate that users can identify and distinguish differing waveforms significantly more effectively than amplitude modulation and frequency. Therefore, different waveforms can be used as the texture parameter in Tacton design.

Previous Tacton design has used amplitude modulation to create the roughness parameter but accuracy was not high enough for reliable use. Given that using differing waveforms produces high recognition rates, by changing the technique used to create texture, overall recognition rates for 3 parameter Tactons could be increased even further thus getting closer to 100%. We will test this in a future experiment.

In order for amplitude modulation to be replaced with different waveforms in Tacton design it will be necessary to combine this new parameter with other vibrotactile parameters such as spatial location to see if there are any negative effects when used in combination. If Tactons are to be used effectively in crossmodal applications with Earcons it will also be necessary to make sure that texture (timbre) in Earcons can transmit the same information as waveform in Tactons.

The number of available usable parameters in the tactile domain is limited and using tactile roughness as a parameter in Tactons produced low recognition rates but the results of this study have shown that tactile texture using different waveforms could be a very successful third parameter for Tacton design.

Acknowledgements

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