# Tactile Crescendos and Sforzandos: Applying Musical Techniques to Tactile Icon Design

**Lorna M. Brown,**
**Stephen A. Brewster**
**& Helen C. Purchase**

Department of Computing Science
University of Glasgow
Glasgow G12 8QQ, UK

lorna@dcs.gla.ac.uk
stephen@dcs.gla.ac.uk
hcp@dcs.gla.ac.uk

www.tactons.org


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## Abstract
Tactile icons (Tactons) are structured vibrotactile messages which can be used for non visual information display. Information is encoded in Tactons by manipulating vibrotactile parameters. This research investigates the possibilities of applying musical techniques to tactile icon design in order to define such parameters. Tactile versions of musical dynamics were created by manipulating the amplitude of vibrations to create increasing, decreasing, and level stimuli and an experiment was carried out to test perception of these stimuli. Identification rates of 92%-100% indicate that these tactile dynamics can be identified and distinguished from each other, and that tactile dynamics could be used in Tacton design.

## Keywords
Tactile icons, Tactons, non-visual interaction.

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

## Introduction
Tactons [3] are structured, abstract, tactile messages which can be used to communicate information non-

visually. They are the tactile counterpart of visual icons and audio Earcons [2] and could be used in computer interfaces in place of, or in combination with, these. Tactons have the potential to improve interaction in a range of different areas, particularly where the visual display is overloaded, limited in size or not available, such as interfaces for blind people or in mobile and wearable devices.

In order to create Tactons, it is necessary to identify parameters of vibration that can be used to encode information. Earcon designers use parameters such as melody, pitch and timbre (musical instrument) drawn directly from the field of music, but the tactile domain does not have an equivalent field from which to draw. However, sound and vibration are both created from the same source and are both senses which are temporal in nature, therefore it seems likely that the fields of music and audio could also be used to inform Tacton design.

Previous studies have identified suitable parameters for Tacton design as rhythm and tactile "roughness" [3]. Both these parameters are derived from audio parameters; rhythm is taken directly from music, while tactile roughness is created in the same way as audio roughness [3]. It has also been shown that musical terms such as tempo (speed) can be used to describe tactile "melodies" [6]. These examples confirm that it may be possible to use music to inform Tacton design.

Blattner [2] proposed the use of musical dynamics in Earcons, specifically the use of crescendos (increases in volume) and decrescendos (decreases in volume). Gunther also suggested that these dynamics, and also accents, would be useful in tactile composition [5]. This study investigates the perception of tactile dynamics to assess the suitability of these techniques for use in Tacton design.

## Stimuli

Tactile dynamics can be created by altering the amplitude or intensity of a vibration. Three types of tactile dynamics were investigated in this study: increases (amplitude increases over time), decreases (amplitude decreases over time) and level stimuli (no change in amplitude over time). Three different types of increase and decrease (linear, exponential and logarithmic) were created in order to investigate which would be the easiest to identify, and therefore most suitable for use in Tacton design. Figures 1 to 3 show the three different types of increase (plotted as amplitude against time). The same three types were used for decreases and the linear decrease is shown in Figure 4.

Pilot testing indicated that it might be difficult to distinguish between increases and level stimuli. This could be due to the fact that the stimulus starts at a low intensity and by the time the user's attention is focused on the stimulus the amplitude has leveled off. In music, an increase in volume over time (known as a crescendo [1]) can be made more obvious to listeners by using a technique called sforzando-piano (sfp) before the crescendo (cresc), and this technique could also be applied to tactile crescendos. A sforzando is a strong accent, and piano means soft/quiet [1], so a sforzando-piano has the effect of a sound which starts with a strong attack and high volume (sforzando), and drops quickly to a very low volume (piano). Combining the sfp with a crescendo (to create a sfp-cresc) means that after the sudden drop in volume, the volume then gradually increases over time (crescendo). This can be seen in Figures 3a and 3b. The high volume accent at the start (sforzando) grabs the listener's attention, making them very aware of the crescendo which follows.

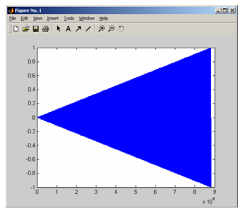

**figure 1:** linear increase

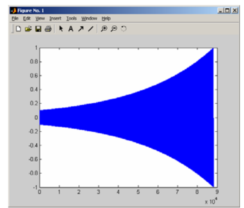

**figure 2:** exponential increase

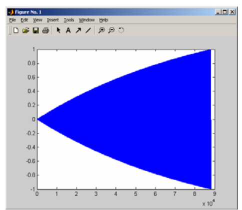

**figure 3:** logarithmic increase

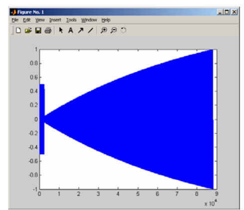

**figure 3a:** logarithmic increase with low intensity sfz

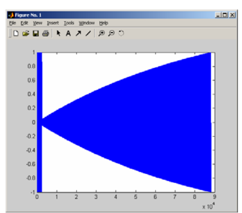

**figure 3b:** logarithmic increase with high intensity sfz

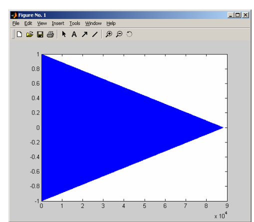

**figure 4:** linear decrease

This sfp-cresc effect was applied to the increase stimuli in order to investigate whether this would improve identification of amplitude increases. Two different amplitude levels were used for the sforzando: a high level, which matched the final level of the stimuli (Figure 3a) and a low level which started at half the level of the final level (Figure 3b). Pilot testing indicated that the lower intensity sforzando was more subtle, and might improve perception of increases, while the higher intensity one might cause confusion as it felt more like a discrete event of its own.

## Tactile Device

The Tactons were presented to users using a TACTAID VBW32 transducer (Figure 5), from Audiological Engineering Corporation (www.tactaid.com) attached to the index finger of their non-dominant hand. The VBW32 is an inertial transducer, which consists of a rigid case, inside which a mass is suspended on a spring. Both the mass and the case vibrate when an alternating electromagnetic force is generated [4], so the user feels the vibrations through the case itself.

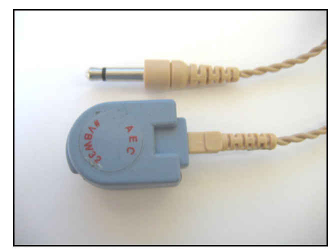

**figure 5:** AEC TACTAID VBW32 transducer

## Aim and Hypotheses

The aim of this experiment was to discover whether participants could identify and distinguish between amplitude increases, decreases and level stimuli, and to identify the most suitable types of increase and decrease for use in Tactons. It also aimed to see whether the use of the musical sfp-crescendo technique would improve perception of increases. The hypotheses were:

1. Participants will be able to distinguish between the 3 types of tactile dynamics (over 90% correct identification).
2. There will be a difference in the ability to recognize an increase between linear, logarithmic and exponential increases.
3. Adding the sfp-cresc effect will improve perception of increases, and avoid confusion with level stimuli.
4. The low intensity sforzando will result in better identification of increases than the higher intensity sforzando as the high intensity sforzando may be perceived as a separate event.
5. There will be a difference in the ability to recognise a decrease between linear, logarithmic and exponential decreases.

## Experimental Procedure

There were 54 tasks in this experiment, consisting of 18 increases (two of each of the nine types), 18 decreases (six of each of the three types), and 18 level stimuli. In each task participants were presented with a two second vibration and asked to identify what happened to the amplitude of the vibration over time. The stimulus was presented four times, with a one second pause between presentations, and participants could respond at any time by selecting the corresponding radio button on a dialogue box. Participants could choose from four options:

1. Overall Increase: Overall, the amplitude of the vibration increases over time
2. Overall Decrease: Overall, the amplitude of the vibration decreases over time
3. Level: The amplitude of the vibration stays constant over time.
4. Other: The amplitude of the vibration does something other than the three options above.

The "Other" category was included in order to identify any confusion caused by the sfp-cresc. If users selected "other" it would indicate that they had perceived the stimulus as something different, not just as an enhancement of the increase. Qualitative data on users' experiences of the experiment were gathered through an interview to identify any confusion that may have arisen from the use of the sfp-cresc stimuli.

Before starting the experiment participants were trained to use the interface by carrying out four tasks from the experiment – identifying a linear increase, linear decrease, linear increase with sforzando-crescendo and a level stimulus. They did not receive any feedback during training or any guidance on what an increase or decrease felt like, as the aim was to identify whether these stimuli were recognizable without training. In particular, they were not trained to recognise the increases containing sforzando-crescendos, as the experiment aimed to identify their instinctive responses to these, rather than to train them to recognise these as increases.

## Results

During the experiment, data were collected on participants' responses to each stimulus. From these data, percentage correct scores were calculated for each stimulus. The average recognition rates for all types (standard increase/decrease/level) were over 80% (Figure 6). These rates improve greatly when only the best stimulus from each type is considered, in which case the identification rates are 100% for increases (linear/exponential), 92% for decreases (linear/exponential) and 95% for level stimuli. Hypothesis 1 can be accepted as these recognition rates are all over 90%.

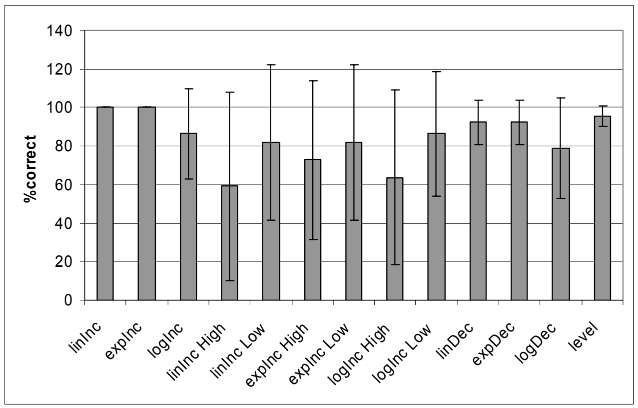


**figure 6:** Percentage correct scores with standard deviations

Linear (linInc) and exponential (expInc) increases were correctly identified 100% of the time. Logarithmic (logInc) increases were correctly identified less often: only 85% of the time (Figure 7). An ANOVA showed a significant difference overall ($F(12,142)=1.99$, $p=0.03$), however post hoc Tukey HSD tests did not show any differences in the individual pairs. Therefore, it is not possible to accept Hypothesis 2.

Hypothesis 3 suggested that the addition of the sforzando-crescendo would improve perception of increases. However, although there were no significant differences between performance on these increases and the standard increases, the addition of the sforzando-crescendo seemed to cause confusion. The large standard deviations indicate that people had very mixed responses to these stimuli. This is backed up by qualitative data which showed that participants were confused by these stimuli. Four subjects thought that the initial pulse was caused by a problem with the transducer or amplifier rather than an intended part of the stimulus. One participant reported that he perceived these stimuli more like parabolas, because they started high, then went low, and then high again. Two participants reported that they knew that these stimuli were increases, but because they were different from standard increases, they selected the "other" option. As there were no significant differences between high and low intensity sforzandos it is not possible to accept Hypothesis 4.

Linear (linDec) and exponential (expDec) decreases were identified correctly 92% of the time, while the identification rate for logarithmic (logDec) decreases was 78% (Figure 6). Hypothesis 5 cannot be accepted as this difference is not statistically significant

## Conclusions and Future Work

This study investigated perception of tactile "dynamics" (increases and decreases in amplitude, and stimuli with no amplitude change). The results, with recognition rates of 92-100% for the best instance of each dynamic type (increase/decrease/level) indicate that these tactile dynamics can be identified and distinguished from each other, and that tactile dynamics could therefore be used as a parameter in Tacton design.

Three different types of amplitude increase (crescendo) and decrease (decrescendo) were tested. The linear and exponential increases reached 100% identification, compared to 85% for the logarithmic increase.

Similarly, linear and exponential decreases had higher identification rates (92%) than logarithmic decreases (78%). While these differences are not significantly significant it would seem appropriate to use either linear or exponential increases and decreases when designing Tactons since they achieved recognition rates of 92-100%.

The addition of a high intensity accent (sforzando) was intended to improve perception of increase stimuli (crescendos), however it caused confusion. While this result suggests that sforzandos should not be used in Tacton design, training users to recognize such stimuli may avoid this confusion, therefore future work should investigate the effect of training. In addition, this attention grabbing technique may be more useful in an interface where the user's full attention is not devoted to the tactile stimuli (e.g. in mobile phone alerts), and future work could evaluate it in this context.

In order for tactile dynamics to be used in Tacton design it will be necessary to combine them with other vibrotactile parameters such as duration, roughness and rhythm. Future work will investigate the effect of combining these parameters in order to understand how they interact. In addition, future studies could investigate the perception of more complex amplitude changes, such as parabolic shapes (e.g. an amplitude increase followed by a decrease), that could be used in the design of Tactons.

The results of this study indicate that the transfer of dynamics such as crescendos and decrescendos from music to the tactile domain is successful, and that they could therefore be used in Tacton design. These results and the previous utilization of techniques such as rhythm, roughness and tempo in the design of tactile messages indicate that it is beneficial to draw from the fields of music and audio when designing Tactons. Future work will investigate whether there are other musical techniques that could be applied to Tactons.


## Acknowledgements

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