Crossmodal Congruence: The Look, Feel and Sound of Touchscreen Widgets

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ABSTRACT

Our research considers the following question: how can visual, audio and tactile feedback be combined in a congruent manner for use with touchscreen graphical widgets? For example, if a touchscreen display presents different styles of visual buttons, what should each of those buttons feel and sound like? This paper presents the results of an experiment conducted to investigate methods of congruently combining visual and combined audio/tactile feedback by manipulating the different parameters of each modality. The results indicate trends with individual visual parameters such as shape, size and height being combined congruently with audio/tactile parameters such as texture, duration and different actuator technologies. We draw further on the experiment results using individual quality ratings to evaluate the perceived quality of our touchscreen buttons then reveal a correlation between perceived quality and crossmodal congruence. The results of this research will enable mobile touchscreen UI designers to create realistic, congruent buttons by selecting the most appropriate audio and tactile counterparts of visual button styles.

Categories and Subject Descriptors

H.5.2 [**User Interfaces**]: Haptic I/O, Auditory (non-speech) feedback, Style guides.

General Terms

Human Factors, Design.

Keywords

Mobile touchscreen interaction, auditory/tactile/visual congruence, touchscreen widgets, crossmodal interaction.

1. INTRODUCTION

Many mobile devices, such as music players, mobile phones and in-car navigation systems, now rely on touchscreen displays and no longer include physical keyboards. Touchscreens are especially useful for mobile devices as they save space by allowing the input and output elements of the device to be combined. Users can now interact with interface widgets such as buttons, sliders and menus displayed on these touchscreens through fingertip interaction.

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Unfortunately, two of the most basic features of GUI buttons are lost in touchscreen interaction: users can no longer physically feel or hear them. For instance, although touchscreen keyboards are based on physical keyboard designs, they do not produce the natural haptic or auditive response that always occurs when a physical button is touched. There have been recent studies into the use of mobile touchscreen devices and the incorporation of virtual tactile feedback with direct manipulation techniques such as fingertip interaction [1] as well as stylus interaction [2]. It has been shown that tactile feedback can be added to button presses using standard mobile phone vibrotactile actuators or special actuators [3 - 5] and can be both pleasant and beneficial to mobile device users, increasing typing speeds and reducing errors [6].

There have also been several investigations into the addition of audio feedback to mobile device buttons [7] showing that sounds increased the amount of data people could enter on a PDA whilst walking and reduced subjective workload. On many commercial touchscreens, audio feedback is added to keyboard buttons already so that the user can hear the 'click' of the button when it is pressed. So far, however, the majority of research on audio and tactile feedback for buttons has been unimodal; the modalities are rarely combined. These studies also tend to focus on the information that can be encoded in the modalities not on the experience of interacting with the graphical widget.

Although mobile touchscreen hardware is now available and previous work has examined ways in which to produce separate audio and tactile feedback, there has been little consideration of any crossmodal issues such as the relationship between a visual widget and its audio/tactile feedback. Our research considers the following question: how can visual and audio/tactile feedback be combined in a congruent and high quality manner for use with touchscreen GUI buttons?

Congruence is a relationship between objects that implies agreement, harmony, conformity or correspondence (American Heritage Dictionary). In terms of this research, we define congruence as an intuitive match or harmony between the designs of feedback from different modalities. The research described here will demonstrate that congruence between modalities is important. For instance, in a smaller study it has already been shown that incongruent audio/haptic feedback when presenting texture can significantly affect users' ability to distinguish different levels of roughness [8]. The driving factor behind this congruence research is our belief that there is a lot more to interacting with a button than simply its function; we have certain pre-conceptions when we see a button as to how it will feel and sound when we press it. For example, one would expect a flat metallic button to feel and sound completely different to a beveled rubber button. If the visual, audio and tactile feedback produced by a button is not congruent, this may lead to a negative user experience and perhaps the perception of a low quality button.

Previous research confirms that tactile and audio feedback can enhance user performance with touchscreen devices [2-7]; the next step is to examine this feedback in-depth to establish the most congruent set. The technology is now available to allow us to create more realistic buttons with congruent combinations of the visual, audio and tactile modalities.

The experiment described in this paper investigates methods of combining visual and audio/tactile feedback by manipulating different parameters of each modality to produce congruent sets of feedback. For example, assume we have a set of GUI touchscreen buttons with different shapes, texture and size as shown in Figure 1.

Figure 1. Example visual touchscreen GUI buttons, from the Apple iPhone, HTC mobile phone, LG mobile phone, Microsoft Windows Mobile and Nokia 770 Internet Tablet.

What should the corresponding audio/tactile feedback be like when the button is touched or clicked? What audio/tactile representations best match the visual representation?

Our crossmodal solution using visual/audio/tactile touchscreen buttons exploits the human ability to perceive and integrate information from different modalities into one complete sensation. We hypothesise that participants will be able to choose combinations of audio, tactile and visual feedback that increase the congruence and perceived quality of interaction with touchscreen widgets. The results of this research will aid mobile touchscreen UI designers in creating realistic, high-quality and congruent buttons with combinations of the visual, audio and tactile modalities. Given a certain visual style of button, the most appropriate audio and tactile counterparts can be selected, and *vice versa*.

2. BACKGROUND WORK

The approach used in this research focuses on a form of redundant crossmodal interaction where touchscreen button feedback is provided through a combination of three modalities. Unlike multimodal interaction, crossmodal interaction uses the different senses to provide the same information [9]. Within the audio and tactile modalities, it is hoped that the different parameters may be manipulated to create congruent sets of feedback to match the visual widgets. Both modalities share temporal and spatial properties so the potential parameters are intensity, rate, texture, rhythmic structure and spatial location. These parameters are amodal i.e. they can specify similar information across modalities [10].

In Figure 1, it could be imagined that the button shown on the left hand side would be congruent with a soft low intensity single vibration to create a rounded smooth feeling combined with an audio beat using a soft timbre with a crescendo followed by a diminuendo (an increase and decrease in amplitude).

Through crossmodal combination we have the option to use all three modalities together resulting in much richer sets of feedback as opposed to using a single modality. It is well known that adding feedback from one modality to the feedback from another modality (for example, adding audio to tactile or *vice versa*) can significantly alter perception [11]. Audio, for example, has many more parameters that may be manipulated compared to the tactile modality (due to the limitations in current tactile actuators), so a greater number of effects can be created using audio plus tactile as opposed to tactile feedback alone. For instance, by simply changing the audio timbre, the perception of tactile texture can change from metallic to soft without ever changing the tactile feedback [8,12].

The effects of individual modalities on the perception of others can be significant. Our different senses receive correlated information about the same external objects and this information is combined in our brains to yield our overall percepts [13]. For this reason, it is important to study the visual, audio and tactile modalities in combination when considering the experience of interacting with a button (or other touchscreen widget).

These effects have been widely studied in the field of perception and psychology with the most famous example being the McGurk effect [14]. The McGurk effect is a phenomenon where our vision alters speech perception (e.g., the sound 'ba' is perceived as 'da' when coupled with a visual lip movement associated with 'ga'). The spatial location of a tactile or audio source can also be significantly influenced by visual stimuli. This effect is known as the 'ventriloquist effect' [15]. There has also been research into the relationship between the tactile and audio modalities. Studies have demonstrated that sounds that are exactly synchronous with hand-rubbing can strongly modify the resulting tactile sensations [16]. These studies indicate that different sensations can be produced when combining modalities that cannot be produced in unimodal displays. They also suggest that by combining visual buttons with audio/tactile feedback the perception of the visual button itself could be significantly altered. Therefore, certain combinations of visual, audio and tactile feedback may be more congruent than others and result in more pleasant, believable and usable interactions.

3. CONGRUENCE EXPERIMENT

This experiment investigated methods of combining visual and audio/tactile feedback congruently using a crossmodal matching methodology: participants were given a visual or audio/tactile button and an event, and had to match the other modalities, i.e. what should it sound, feel and look like when the button is clicked?

3.1 The Mobile Touchscreen Device

The device used in this research was a Nokia 770 Internet Tablet (Figure 2) a commercially available handheld device which has been augmented with piezo-electric actuators [17] and a standard vibration motor [18]. Tactile stimuli were created with a proprietary script language implemented on the device.

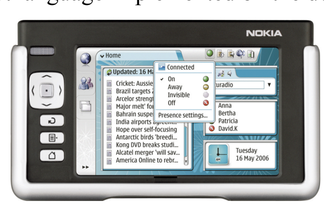

Figure 2: Nokia 770 Internet tablet.

3.2 Physical Button Investigation

Given that current touchscreen keyboard designs are based on physical QWERTY or number keyboards, it was decided that our touchscreen button designs should be based on the 'good old fashioned' physical buttons.

Figure 3: The ten different physical buttons studied.

There are few existing guidelines on the design of touchscreen buttons and most guidelines for UI design [19] focus on the purpose of each button and the spacing between buttons etc. but not on the actual design of the button itself. There are also few guidelines of the design of physical buttons for keypads [20] so we decided to purchase ten different physical buttons and studied their designs in order to establish their basic design parameters and to compare their mechanical characteristics when pressed (Figure 3).

Various key design features were discovered through examination of the buttons, several of which can be recreated virtually in the audio and tactile modalities on a touchscreen display as shown in Table 1.

4. STIMULI

4.1 Visual Button Styles

After an analysis of traditional physical buttons, three basic parameters were chosen for the initial touchscreen visual button styles: shape, size, and height.

Shape: the majority of physical buttons on standard devices are based on either rectangles or circles so these shapes were chosen for the touchscreen buttons (Figure 4). This also allowed us to keep the first experiment in this research area simple and well defined.

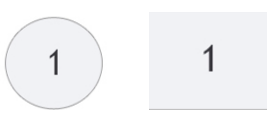

Figure 4: Visual touchscreen button shapes.

Size: it was observed during pilot studies that the size of the button might affect user perception during interaction. For this reason, two different button sizes were used. Small touchscreen buttons were 6mm x 4.5mm. Large touchscreen buttons were the maximum size they could be (9mm x 7mm) while still fitting on the N770 display meaning that the whole height of the display was filled with the number keypad.

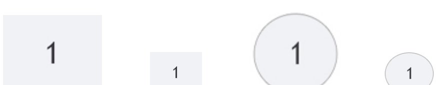

Figure 5: Visual touchscreen large and small button sizes.

Height: physical buttons can be of different heights or depths. The touchscreen buttons used in this study were either completely flat or raised (Figure 6).

Figure 6: Raised and flat visual touchscreen buttons.

According to our pilot studies, the visual appearance of a keypad vs. a single button can also affect congruence ratings. We chose to use a number keypad (Figure 11) instead of a single button since pressing keys on a keypad is closer to the natural usage of a device. We chose a number keypad over a QWERTY keyboard because it fits better on the screen and it gave us more freedom to play with the size of the keys.

Table 1: Physical Button Properties.

Feature	***Description***	***Can It Be Recreated On A Touchscreen?***
Size	Length and width of the button	Yes, through the visual modality. We also hypothesise that the duration and intensity of audio/tactile feedback could affect perception of size.
Shape	Some mobile devices use various different shapes on their keypads	Yes, different shapes can be drawn visually on the touchscreen.
Colour	The colour of the button and any functional text	Yes, through the visual modality.
Texture	The texture of the button material e.g. a plastic button may feel smooth to touch compared to a rougher rubber button	Yes, audio texture can be created using different timbres while tactile texture can be created using amplitude modulation, random rhythmic structures or waveforms. Visual textures can be drawn on the buttons.
Weight	The amount of pressure required to fully depress the button	Yes, the threshold of the touch panel can be set to simulate the amount of pressure needed.
Snap Ratio	The difference between weight and contact force (amount of pressure to keep the button down) divided by weight	Yes, this could be simulated with audio/tactile feedback.
Height	The distance from the bottom of the button on the surrounding surface to the top of the button	Yes, we hypothesise that displacement produced by piezo actuators could affect height perception as well as intensity and duration i.e. a short weak burst of tactile feedback may be more likely to come from a flat button while a powerful long burst may suit a taller button taking longer to push.
Travel Friction	How smoothly the button moves when pushed	Yes, different audio/tactile textures can be presented during the button press.
Surround	The material of the surface on which the button is mounted, the gap between buttons, how it feels for the finger to move from the button to the surrounding	Yes, the visual representation of the button can include gaps and the surrounding surface texture can be created using all three modalities.

4.2 Visual Feedback

The only visual feedback provided by the buttons was the standard feedback found in GTK (a cross-platform widget toolkit for creating graphical user interfaces: www.gtk.org) buttons when clicked on the N770 (Figure 7). The different visual styles used were, circle/rectangle, small/large and flat/raised buttons.

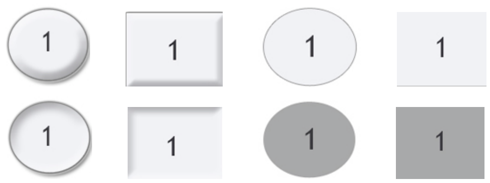

Figure 7: Non-clicked and clicked visual touchscreen buttons.

4.3 Audio/Tactile Feedback Design

Two different types of actuator hardware were chosen in this experiment to produce different types of tactile feedback to allow us to investigate whether, depending on the visual style, different tactile hardware might be appropriate. The piezo-electric feedback solution can create short more display localized tactile bursts, by moving the touch screen display module within the device [17]. The piezo is also able to generate single-transients resembling the tactile feedback in physical buttons. The conventional vibrotactile feedback solution is optimized for longer vibrotactile stimuli, where the whole device mass shakes without any localisation [18]. The audio feedback used in the stimuli was the natural audio produced by the tactile actuators.

We used four different kinds of audio/tactile stimuli in the experiment. In general we call them “clicks”, since they are designed for buttons. Two of these were implemented with piezo and two of them with vibrotactile feedback. We created a gentle and a stronger click with both actuators, resulting in four different clicks. We named the clicks as follows to describe the characteristics of the stimuli:

- Piezo 1: soft click
- Piezo 2: “clicky” click
- Vibra 1: soft click
- Vibra 2: long rough click

4.3.1 Tactile Feedback Properties

Despite the large amounts of multimodal research in existence, no formal method has been established to describe tactile feedback. It can be very difficult to describe, in words, the tactile sensations felt by the user. For this reason, a basic method of describing the properties of tactile feedback based on kinetic energy is presented below. This enables the stimulus to be described in a technology-independent way. In this case it is used to compare output from different types of tactile actuator solutions based on piezo actuators and a vibration motor.

Kinetic energy is the source of the strain energy density which relates to the neural response of human mechanoreceptors [21]. Using straightforward displacement measurements of the vibration of the device, it is possible to define the total kinetic energy of the stimulus. This method assumes that the user’s fingers are touching or holding the vibrating surface and do not significantly dampen the vibration. In Figure 8 and Figure 9, there are example displacement graphs of Piezo 1: soft click and Vibra 1: soft click, as measured by a laser vibrometer system with 20 kHz sampling frequency.

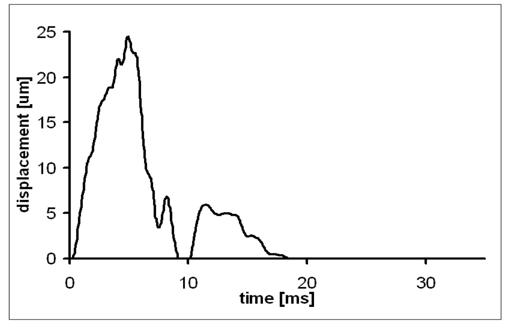

Figure 8: Displacement figure of Piezo 1: soft click.

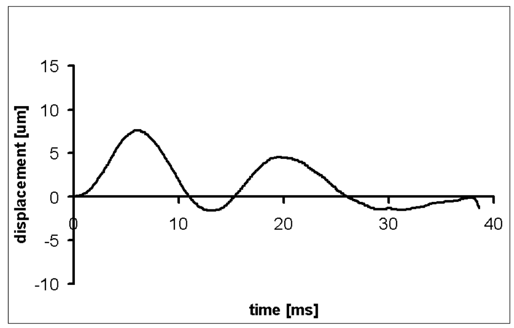

Figure 9: Displacement figure of Vibra 1: soft click.

Physical fundamentals state that kinetic energy (E) is dependent on vibrating mass (m):

$$E = \frac{1}{2}mv^2$$

In our solutions, the piezo actuators only shake the display module, with a mass of 49 grams while vibrotactile actuators move the whole device body, with a mass of 183 grams. In both cases the oscillating masses and stiffness of the actuator systems are large enough so the hand damping properties [22] can be ignored.

Figure 10 shows an example of determined kinetic energy of the Vibra 1: soft click stimulus. Since the sampling frequency (20 kHz) of the measurements was much higher than the human haptic sensation bandwidth, a longer time window of 0.25 ms was chosen. The kinetic energy was integrated from the displacement measurements with the time window chosen.

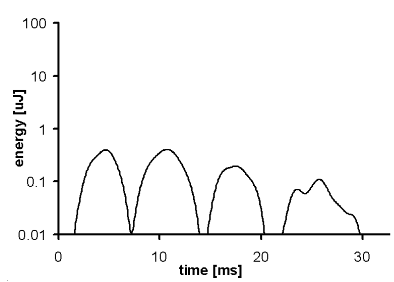

Figure 10: Kinetic energy of Vibra 1: soft click.

Along with the kinetic energy, the physical parameters of the stimuli from a designer’s point of view are detailed in Table 2, with a comparison of the different actuators used.

Table 2: Physical parameters of the four different tactile clicks.

Stimulus	*Duration (ms)*	*Displace-ment (μm)*	*Maximum kinetic energy (μJ)*
Vibra 1: soft click	30	7	0.4
Vibra 2: long rough click	45	12	4
Piezo 1: soft click	8	22	10
Piezo 2: 'clicky' click	5	17	12

4.3.2 Audio Feedback Properties

The stimuli used in most tactile interactions studies in the mobile device domain fall within the frequency range of both tactile [23, 24] and audio modalities [25]. This is also the case for the stimuli used in this experiment. Therefore the tactile actuators always intrinsically produce audio stimuli at the same time. Therefore, to fully describe the stimulus, this self-produced audio stimulus also needs to be determined.

The amplitude and dominant frequency properties of this self-produced audio are summarised in Table 33. We also measured two physical keyboards on other mobile devices in order to compare the figures with the virtual click measurements. The keyboards measured were a Lenovo T61p laptop keyboard, and a Nokia N95 mobile phone keypad. The audio signals were digitally recorded on a laptop with a microphone, and analysed later with Matlab in order to find the dominant frequencies. Audio pressure was determined using an A-weighted sound level meter.

According to the audio analysis, it is clear that the frequency bands in which the kinetic energy is produced determines the ratio between the tactile and audio stimuli. The sharper piezo bursts, e.g. our experimental stimuli created with piezo, result in a higher intensity of audio output compared to haptic due to the higher frequency level whereas the lower frequencies produced by the vibration motor, e.g. our experimental stimuli with vibration motor, result in lower levels of audio output compared to haptic.

Table 3: Properties of self-produced audio in our tactile clicks compared to two physical keyboards.

Stimulus	*Volume (dB)*	*Dominant frequency (-ies) (Hz)*
Vibra 1: soft click	45	90
Vibra 2: long rough click	48	150
Piezo 1: soft click	62	70, 320
Piezo 2: 'clicky' click	63	460, 600
Lenovo T61p Keyboard	60	180
Nokia N95 Keypad	48	320, 700

4.4 Hypothesis and Methodology

The hypothesis in this experiment was that participants would be able to match different types of audio/tactile feedback to different visual styles of button.

A standard paired-comparison method where a range of options is compared and the results are tallied to find an overall winner. A range of plausible options is listed. Each option is compared against each of the other options, determining the preferred one in each case. The results are tallied and the option with the highest score is the preferred option.

Twelve people took part in the experiment, 8 male and 4 female. They were all employees of Nokia Research Center, all right-handed, and aged between 23 and 47. The experimental method used was a within-subjects design where each participant was tested on all four conditions: Piezo 1: soft click, Piezo 2: 'clicky' click, Vibra 1: soft click and Vibra 2: rough click in a counterbalanced order.

There were 48 tasks in this experiment, 8 different visual touchscreen button designs were used with each combination pair of the four tactile click conditions. The experiment interface is shown in Figure 11. In each task participants were shown the visual representation of the touchscreen button as part of a number pad and then presented with two sets of tactile feedback (accessed using the A and B buttons on the interface). Users were able to explore the keypad and the two audio/tactile clicks for as long as they liked until they were ready to answer. They were asked to pick which of the two clicks given (a combination pair of Piezo 1, Piezo 2, Vibra 1 or Vibra 2) best matched the visual button. For instance, in an example task participants would be presented with a number keypad consisting of small raised circular buttons. Upon selecting the 'A' radio button, the participants would feel tactile feedback set 'A' (a random choice of Piezo 1, Piezo 2, Vibra 1 or Vibra 2) when pressing the touchscreen keypad (along with the associated self-produced audio). Then, participants could switch to tactile feedback set 'B' and feel a different tactile click (once again a random choice of Piezo 1, Piezo 2, Vibra 1 or Vibra 2) when touching the buttons. The participants were asked to choose which tactile feedback set (A or B) matched the visual style of button best and press the 'Submit' button at the bottom of the screen to submit their preference.

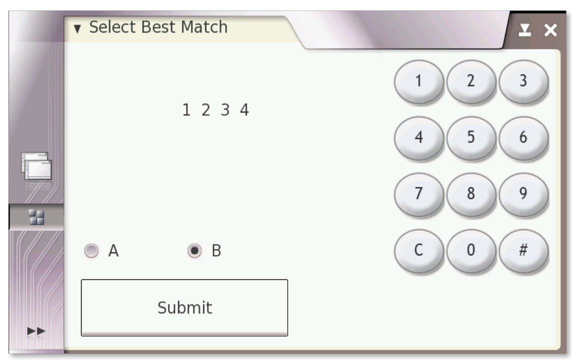

Figure 11: Screenshot of the experiment interface on the Nokia 770.

Before beginning the experiment participants were given a short tutorial to introduce them to the concept of touchscreens, tactile feedback and congruence. They were then allowed to familiarise themselves with the experiment software running on the N770 before beginning the actual tasks.

4.5 Results

During the experiment, the experimental software recorded data on the participants' rankings of each stimulus (the number of times each audio/tactile feedback set was chosen as the preferred match to the given visual button style). The number of votes for each type of audio/tactile feedback given a visual button style is shown in Figure 12.

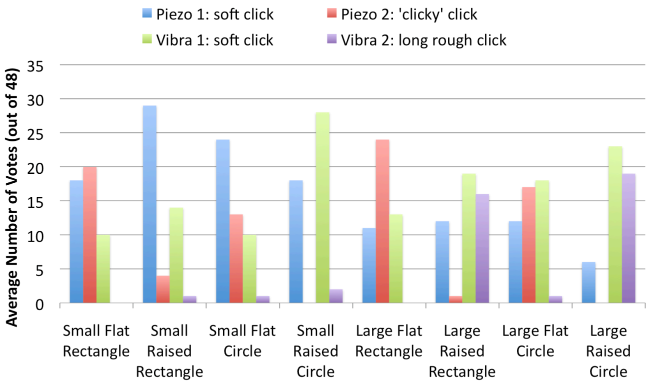

Figure 12: Number of votes for each audio/tactile feedback style (when given a visual button style).

Overall Vibra 1: soft click is ranked highest with a total of 135 out of a possible 384 votes, then Piezo 1: soft click with 130 votes, followed by Piezo 2: 'clicky' click with 79 votes with Vibra 2: long rough click receiving the least votes with a total of 40. These figures suggest that audio/tactile feedback through a soft click from a vibrotactile rotational motor is generally preferred. However, none of the tactile feedback styles achieved 100% of the votes for any of the visual styles. This could be due to the subjective nature of congruence and could indicate that each participant had a different idea as to how each button should feel based on previous experiences with devices and physical buttons. Other possibilities could be that the actuators are not sophisticated enough or the tactile click design is simply not congruent enough with the visual button appearance.

To investigate further it is necessary to break the results down so that the most congruent tactile feedback can be found for each individual button style. For example, although Piezo 2: 'clicky' click received a low number of votes, it received the majority of votes as the best match for large flat rectangle buttons. It simply was not congruent when combined with other visual button styles.

The results show that the Piezo 1: soft click received considerably more votes as a match for small raised rectangle and small flat circle visual buttons. This suggests that congruent touchscreen buttons could be created using small raised rectangles or small flat circles with soft piezo tactile feedback when clicked.

Piezo 2: 'clicky' click does not appear to match with large or small raised circle buttons but it did receive a notably higher number of votes as a match for large flat rectangles and the highest number of votes for small flat rectangles. Therefore, congruent touchscreen buttons with Piezo 2: 'clicky' click feedback when pressed can be created by using a large or small flat rectangular visual style.

Vibra 1: soft click received a higher number of votes when matched with small raised circle buttons while both Vibra 1: soft click and Vibra 2: 'clicky' click scored a high number of votes when matched with large raised rectangles and circles. This suggests that congruent touchscreen buttons could be created using small raised circle buttons with soft vibra feedback when clicked or by adding any of the vibra feedbacks to large raised rectangular or circular visual buttons.

Figure 13 shows the trends in the number of votes for each audio/tactile feedback type for the two visual touchscreen button sizes.

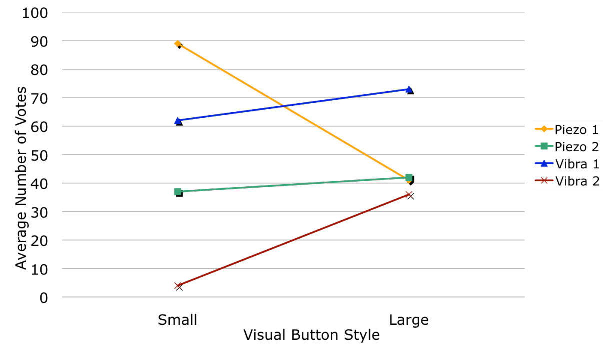

Figure 13: Number of votes for each audio/tactile feedback style when the visual button size changes from small (6mm x 4,5mm) to large (9mm x 7mm).

It can be seen that the number of votes for Piezo 1: soft click decreases by 26% as the visual size increases while the number of votes for Vibra 2: rough click increases by 17% as the visual size increases. Statistical analysis shows that the number of votes for Piezo 1 in small buttons is significantly higher than for Piezo 2 and Vibra 2. The number of votes for Vibra 1 is also significantly higher than Vibra 2. As for large buttons, significantly more votes were placed for Vibra 1 than Vibra 2 ($F = 7.17$, $p = 0.005$).

Figure 14 shows that the number of votes for Vibra 1: soft click and Vibra 2: long rough click increase as the height changes. It also shows the number of votes for Piezo 2: 'clicky' click steeply decreases by 39% as the height changes from flat to raised while the height of the button seems to have no effect on the number of votes for Piezo 1: soft click. There were significantly more votes for all styles over Vibra 2 ($F = 5.3$, $p=0.01$) for flat buttons while for raised buttons; Piezo 1 and Vibra 1 received significantly more votes than Piezo 2 and Vibra 2.

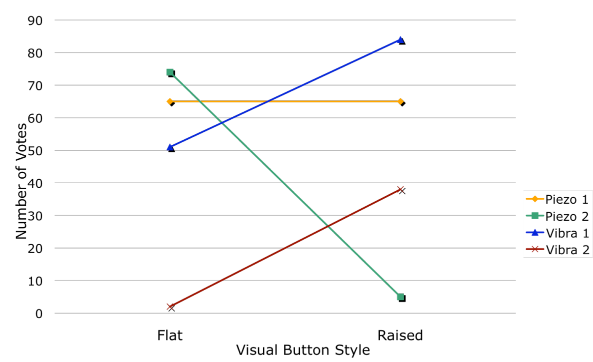

Figure 14: Number of votes for each audio/tactile feedback style when visual button height is flat and raised.

Although explicit values cannot be extrapolated, Figure 15 effectively shows the trends of individual results for different visual button shapes. It can be seen that the number of votes for Vibra 1: soft click increases by 12% as the shape changes from a rectangle to a circle while the number of votes for Piezo 1: soft click and Piezo 2: 'clicky' click slightly decrease by 5% and 10% respectively as the shape changes from a rectangle to a circle. Vibra 2 received significantly less votes than the others for rectangles ($F=1.83$, $p = 0.19$) and Piezo 1 received significantly more votes than Piezo 2. For circles, Piezo 1 and Vibra 1 received significantly more votes than Piezo 2 and Vibra 2. The number of votes for Vibra 1 was also significantly higher than Piezo 1.

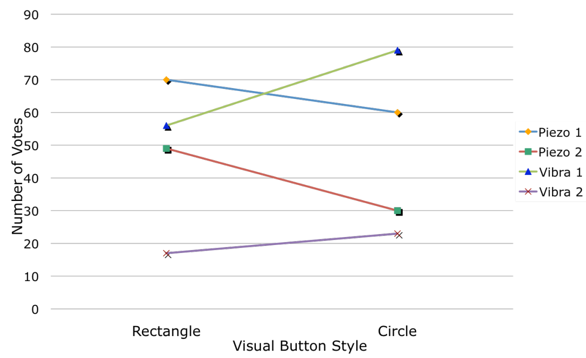

Figure 15: Number of votes for each audio/tactile feedback style for circular and rectangular button shapes.

4.6 Quality and Congruence

Qualitative data were also collected during the experiment by means of a questionnaire at the end of the session. Participants were presented with all combinations of visual and tactile feedback and asked to rate the quality of each set using a seven point Likert scale ranging from 'low quality' to 'high quality'. Participants were asked to rate the quality of the 'whole' button; not the individual sets of audio/tactile feedback but the experience of interacting with the button itself. In terms of this research, quality is measured through the level of enjoyment when interacting with the button; whether they are of a high standard or not. The average perceived quality for each visual and audio/tactile combination is shown in Figure 16.

Originally, the quality questionnaires used in this experiment were intended to produce separate results from the quantative congruence data collected during the experiment sessions with participants. However, upon examining the data, there were obvious similarities so a correlation analysis was performed. From the average number of congruence votes for each crossmodal combination and average ratings of quality we found a significant correlation of 0.79 ($r = 0.349$, $p = 0.05$) showing a positive relationship between congruence and quality. This unexpectedly significant correlation suggests that a higher level of crossmodal congruence resulted in a higher rating of overall button quality.

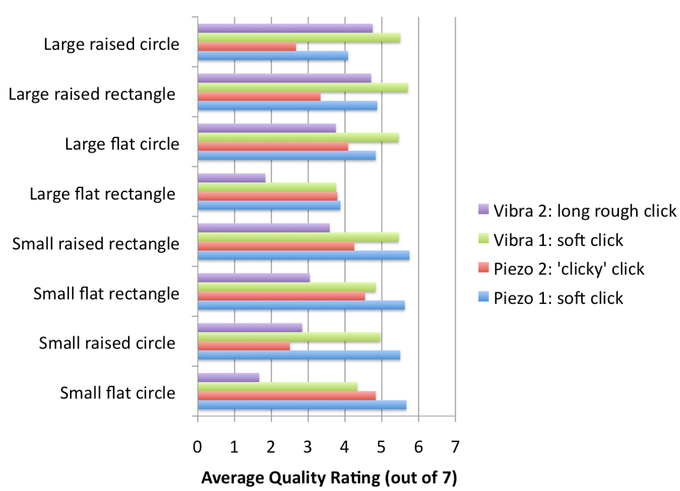

Figure 16: Average rating of quality (or congruence) for each crossmodal touchscreen button.

Figure 16 could be said to represent the congruence of the visual, audio/tactile feedback where large raised rectangles with Vibra 1 feedback result in the highest level of congruence and quality implying that these are the most realistic buttons. The results show that the small flat circular button with rough vibra feedback was rated the lowest in quality and is therefore the least congruent combination of modalities. Both Vibra 1: soft click and Piezo 1: soft click were consistently rated as higher quality than Vibra 2: long rough click and Piezo 2: 'clicky' click. There were notable differences in quality ratings. Vibra 1: soft click and Piezo 1: soft click received considerably higher ratings of quality than Vibra 2: long rough click and Piezo 2: 'clicky click when combined with the small raised circle visual style, the large raised rectangle, the small raised rectangle and the small flat rectangular visual style of button.

4.7 Summary and Future Studies

The results can be summarized as follows from a UI design point of view:

- Circular touchscreen buttons are most congruent with:
  - Small:
    - Flat: soft piezo clicks
    - Raised: soft vibra clicks
  - Large:
    - Flat and Raised: soft vibra clicks
- Rectangular touchscreen buttons are most congruent with:
  - Small:
    - Flat: short sharp 'clicky' piezo clicks
    - Raised: soft piezo click
  - Large:
    - Flat: short sharp 'clicky' piezo clicks
    - Raised: soft vibra clicks

Further congruence studies will investigate the audio modality controlled independently from the tactile. There are more parameters in the audio domain that may be manipulated which means that, a greater number of sensations may be created by simply changing the audio while the tactile remains the same. Following on from this, more of the tactile parameters will be incorporated into the feedback (for instance, duration, delay, and rhythm) along with a greater number of visual styles.

In this experiment the button down click event was investigated. However, there are many more events triggered through interaction with a button and different sets of feedback may be more or less appropriate depending on the event. Future studies could include 'up-clicks' and 'slips'. Lastly, following on from buttons, congruent sets of feedback could be created for other touchscreen graphical widgets such as scrollbars and progress bars while dynamic feedback could be created for 'drag and drop' events.

5. CONCLUSIONS

This paper has focused on how congruent sets of visual and audio/tactile feedback can be created for mobile touchscreen buttons. A paired-comparison experiment was conducted revealing relationships between individual visual button features such as size, shape and height with audio/tactile properties.

The tactile clicks produced by the vibrotactile motor tended to be chosen as a congruent match with raised buttons. Generally, the tactile clicks generated by the vibrotactile motor are much longer than the ones generated by the piezo. In contrast their displacement and maximum kinetic energy is smaller. This combination makes the feedback “rounder” than shorter feedbacks with high displacement and high kinetic energy. The “roundness” of the feedback seems to be congruent with the raised visual appearance. The extremely sharp ‘clicky’ click from the piezo actuators was congruent with rectangular buttons rather than circular ones. The reason for this could be that the edges of rectangular buttons were sharp and abrupt much like the piezo feedback. Overall, the soft piezo click, which consisted of a lower displacement than the others, lasting 8ms (slightly longer than the sharper ‘clicky’ piezo click, and a great deal shorter than the vibrotactile feedbacks) was chosen as a congruent match the majority of the time for small buttons and consistently produced high quality ratings.

The analysis of perceived quality of our touchscreen buttons uncovered a positive correlation between congruence of visual and audio/tactile feedback with the overall perceived quality of the button as a whole. There is a great deal more to interacting with a button than its function and visual appearance. We have shown that by choosing congruent sets of audio/tactile feedback to be added to touchscreen visual buttons, not only are users’ pre-conceptions of how the button should feel and sound met but also the perceived quality of the buttons is improved. The results of this research will enable mobile touchscreen UI designers to create high quality, congruent buttons by selecting the most appropriate audio and tactile counterparts of visual button styles.

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