

# Feel-Good Touch: Finding the Most Pleasant Tactile Feedback for a Mobile Touch Screen Button

Emilia Koskinen, Topi Kaaresoja and Pauli Laitinen

Nokia Research Center

P.O. Box 407 FI-00045 Nokia Group, Finland

{emilia.koskinen, topi.kaaresoja, pauli.laitinen} @nokia.com

## ABSTRACT

Earlier research has shown the benefits of tactile feedback for touch screen widgets in all metrics: performance, usability and user experience. In our current research the goal was to go deeper in understanding the characteristics of a tactile click for virtual buttons. More specifically we wanted to find a tactile click which is the most pleasant to use with a finger. We used two actuator solutions in a small mobile touch screen: piezo actuators or a standard vibration motor. We conducted three experiments: The first and second experiments aimed to find the most pleasant tactile feedback done with the piezo actuators or a vibration motor, respectively, and the third one combined and compared the results from the first two experiments. The results from the first two experiments showed significant differences for the perceived pleasantness of the tactile clicks, and we used these most pleasant clicks in the comparison experiment in addition to the condition with no tactile feedback. Our findings confirmed results from earlier studies showing that tactile feedback is superior to a non-tactile condition when virtual buttons are used with the finger regardless of the technology behind the tactile feedback. Another finding suggests that the users perceived the feedback done with piezo actuators slightly more pleasant than the vibration motor based feedback, although not statistically significantly. These results indicate that it is possible to modify the characteristics of the virtual button tactile clicks towards the most pleasant ones, and on the other hand this knowledge can help designers to create better touch screen virtual buttons and keyboards.

## Categories and Subject Descriptors

H 5.2 [User Interfaces]: Haptic I/O, Ergonomics, Evaluation/Methodology, Input devices and strategies.

**General Terms:** Human Factors, Design.

**Keywords:** Mobile touch screen interaction, tactile feedback pleasantness, virtual buttons.

## 1. INTRODUCTION

Mobile phones, those small pocket-sized gadgets, which over 3

Permission to make digital or hard copies of all or part of this work for personal or classroom use is granted without fee provided that copies are not made or distributed for profit or commercial advantage and that copies bear this notice and the full citation on the first page. To copy otherwise, or republish, to post on servers or to redistribute to lists, requires prior specific permission and/or a fee.

ICMI'08, October 20–22, 2008, Chania, Crete, Greece.

Copyright 2008 ACM 978-1-60558-198-9/08/10...\$5.00.

billion people carry almost all the time, were initially designed for mobile communication. These days many of them are more like small-sized computers, which allow users to read and write email messages, browse the web, listen to music, take pictures, and navigate their way with the help of digital maps and GPS. All of this can happen anywhere and anytime, which sets special requirements for the usability of these devices.

Originally most mobile phone design included a visual screen and a small physical keypad or keyboard but this is now changing. At the moment there are many mobile phones and other mobile communication devices equipped with a touch screen in the market and more are coming out. Touch screens are not new, as they have been widely used for quite some time in other kinds of devices e.g. in personal digital assistants, but now they are becoming a mainstream technology in mobile communication devices. The Nokia N800 Internet Tablet (Figure 1) is a good example of a typical touch screen mobile communication device, which has a large screen without any physical keyboard and all interaction is done with a stylus.



**Figure 1. The Nokia N800 Internet Tablet, a touch screen device, which uses a stylus for interaction.**

However, almost all of the newest touch screen mobile devices have one major change compared to previous mobile devices such as the Nokia N800: the users can interact with the device using their fingertip instead of a stylus. This seems to be the trend, which touch screen mobile devices are going towards, with most manufacturers getting rid of stylus interaction completely. One well-known finger-operated touch screen mobile device at the moment is the Apple iPhone (Figure 2).

However, finger-operated (and stylus-operated) touch screen mobile devices have one major disadvantage compared to traditional devices with physical keypads, namely the lack of tactile feedback i.e. feedback that can be felt. However, to address this, there are many new touch screen mobile devices coming out

which already feature tactile feedback. For example some Samsung [1] and LG mobile phones [2] are using Immersion's VibeTonz System [3] to provide tactile feedback for touch screen interactions.

Earlier research has shown that tactile feedback enhances the usability and user experience of a touch screen device compared to a device without tactile feedback. This paper presents two experiments investigating the perceived pleasantness of different tactile clicks for virtual touch screen buttons when using two different technologies to produce the tactile feedback. In the experiments we aim to find the most pleasant tactile feedback implemented with both technologies for finger-used virtual buttons. The third experiment then compares these two tactile feedback conditions in terms of usability. The equipment used in this work is capable of providing high-fidelity, high-resolution tactile feedback enabling detailed design of tactile button clicks.



Figure 2. The Apple iPhone touch screen mobile device.

## 2. EARLIER WORK

Poupyrev *et al.* [4] introduced a haptic touch screen and the concept to add the sensation of touch to different GUI (Graphical User Interface) elements, including buttons. They reported that tactile feedback was exceptionally well received and was most effective when the GUI elements needed to be held down or dragged on the screen. Lee *et al.* [5] introduced a concept of different button feelings to the touch screen interaction using a special haptic pen. Work by Nashel *et al.* [6] presents a concept adding tactile feeling to the mobile touch screen buttons helping the user find the button edges.

Fukumoto *et al.* [7] reported a short evaluation of their Active Click tactile touch screen interface. They tested number entry with tactile feedback presented when a button was pressed, and number entry without the tactile feedback, where audio feedback was presented instead. The test was conducted both in silent and noisy situations. They found that tactile feedback can improve the usability of touch screen devices, especially in noisy environments. The results showed that the task time was reduced 5% with the tactile feedback condition compared to the audio feedback condition in a quiet situation and 15% in a noisy situation.

Brewster *et al.* [8] conducted a laboratory and a field test comparing standard virtual buttons to ones with tactile feedback added in text entry task when using a stylus. They used two tactile

stimuli: one to indicate a successful button press and another one to indicate an error. In the field test, participants sat in a seat on an underground train while performing the test task. They found that in the laboratory test participants could perform much better with tactile feedback; they entered more text, made fewer errors and noticed more of the errors they made. The results also showed that participants strongly favored the tactile feedback condition.

Recently, Hoggan *et al.* [9] reported an experiment where they compared devices with a physical keyboard, a standard touch screen and a touch screen with added tactile feedback. They found that adding tactile feedback to the touch screen improved significantly finger based text entry. Their paper proves that tactile feedback is superior to non-tactile feedback case when touch screen buttons are used with fingers.

As it is mentioned in another work by Poupyrev *et al.* work [10], the tactile feedback should also feel good i.e. should be pleasant to use. There are currently no reported studies that we are aware of that have researched the pleasantness of tactile feedback on a touch screen when using fingers on the screen for interaction.

In human-computer interaction usability refers to the ease, efficiency and satisfaction of use [11]. Satisfaction implies that the product should be pleasant to use, so that users are subjectively satisfied when using the product. When considering tactile feedback for touch screen virtual buttons it is important that the feedback itself is perceived as pleasant. Therefore the experiments presented in this paper research the pleasantness of different kinds of tactile stimuli.

## 3. OVERVIEW OF THE EXPERIMENTS

### 3.1 Objectives

The three experiments, which are presented in this paper, try to gain a better understanding of how tactile feedback should be designed for touch screen virtual buttons in mobile devices. The objective was to find the optimal solution from user's perspective to create tactile feedback on a touch screen. The first two experiments examine different tactile feedbacks and aim to find the most pleasant tactile stimuli for the virtual button with piezo actuators or vibration motor technology, respectively, when using a finger for interaction on a touch screen. In these two experiments we wanted to minimize the effect of the design of a keypad and used only two virtual buttons for comparing different feedbacks. In the experiments we used a standard pairwise comparison method for the evaluation. The third experiment then compares the two most pleasant touch screen virtual button tactile feedbacks found in the first two experiments in addition to non-tactile condition in terms of usability in a realistic task.

### 3.2 Hypotheses

We hypothesize that the users are able to tell the difference in pleasantness of the tested stimuli. We also hypothesize that the most pleasant tactile stimulus done with piezo actuators will be preferred over the one done with a vibration motor since we can get more hi-fidelity and that way more realistic clicks for virtual buttons with piezo.

### 3.3 Equipment and Software

We used two proprietary experimental handheld devices identical in appearance in all three experiments. One of them is shown in Figure 3. The devices were 143x73x21 mm in size and display size being 80x40mm (3.5"). They were both connected to a laptop PC with a serial and a display cable. The experiment software written in Java was running in the PC and it displayed the application on the experimental devices' display via the display cable. The device used in the Experiment 1 was the same device used in [12]. It was featured by tactile feedback provided by piezo actuator solution [13]. In this solution, tactile feedback is concentrated to move the display mass, which is 20% of the whole device mass, providing large displacement with rapid responses, but with less kinetic energy compared to traditional vibration motor systems.



**Figure 3. The experiments were made with a proprietary handheld devices (one shown) with a large touch screen.**

In the other device used in the Experiment 2 the tactile stimuli were generated by a vibration motor solution [14], where a vibrator motor shakes the whole device body, a mass of 220 grams. In Experiment 3 we used both devices, and for the non-feedback condition we used the device from Experiment 1 with tactile feedback disabled.

### 3.4 Determining the stimuli properties

In determining the explicit physical properties of provided tactile feedback pulses we use a method described in [15], where all the vibration of each stimuli were experimentally measured. From measurements physical properties of stimuli were determined in terms of total duration and maximum displacement of the stimulus (Table 1 and Table 2). Also self-produced sounds of the stimuli were determined in terms of audio pressures. The audio measurements were done with a sound level meter at a 35 cm distance from the devices.

## 4. EXPERIMENT 1: PIEZO

The first experiment researched the subjectively perceived pleasantness of tactile feedback and the effects of the integration of audio and tactile feedback on a piezo actuator enhanced touch screen device.

### 4.1 Stimuli

The tactile stimulus was generated by a piezo actuator solution, which enables the production of various pulse shapes, with displacement on a scale of several hundred micrometers. The modulation of the stimuli was done by controlling the driving voltage and the current of the piezo actuator and thereby altering two parameters, the rise time and the displacement amplitude. Seven different feedback stimuli were composed altering the amplitude and rise times of the feedback pulses. The different feedback stimuli were chosen according to previous experiment, [12] which investigated the subjectively perceived strength of tactile pulses. All seven of the chosen tactile stimuli used in this experiment were rated between 2 and 4 by the test users on a 1-to-5 (weak to strong) rating scale. The feedback was presented both when the button was pressed and released.

The piezo actuator also produces sound while actuating. The audio feedbacks were not separately designed, but the intrinsic sounds generated by the piezo actuator were used as part of the stimuli in the first part of the experiment. The maximum sound levels associated with stimuli varied between 42 dB to 61 dB.

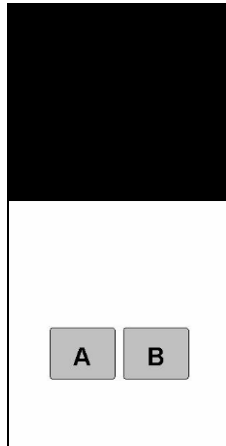
**Table 1. Stimuli parameter values for Experiment 1.**

<i>Stimulus</i>	<i>Drive current (mA)</i>	<i>Total Duration (ms)</i>	<i>Maximum Displacement (<math>\mu\text{m}</math>)</i>	<i>Audio volume (dB)</i>
Piezo 1	180	11	47	61
Piezo 2	180	11	88	60
Piezo 3	46	11	58	49
Piezo 4	17	30	30	42
Piezo 5	46	13	105	46
Piezo 6	46	15	170	45
Piezo 7	17	15	110	42

### 4.2 Methodology

Ten participants took part in the study: six males and four females, all employees of Nokia Research Center. The age of the participants varied from 23 to 39 years, average age being 29 years. All the test users were right-handed and they all used their right hand's thumb to press the virtual buttons on the touch screen. None of the test users had earlier experience with tactile feedback on touch screen. The experiment was conducted in an office room where test users sat in silence when using the touch screen device. The experimental software displayed two virtual buttons, 12x9 mm in size (Figure 4), which provided tactile feedback both when pressed and released. The visual feedback used with the touch screen buttons was minimal: when a button was pressed the color of the button changed and when released the color changed back to the original. The test consisted of two parts, one part with tactile and audio stimuli and the other part with tactile stimuli only. In the tactile only part, test users wore headphones to hear typical street noise from the tape, which masked all the intrinsic audio from the tactile stimuli. Half of the test users did the audio-tactile condition first, and half of them started with tactile-only condition. Altogether, seven different physical stimuli were tested with a pairwise comparison method,

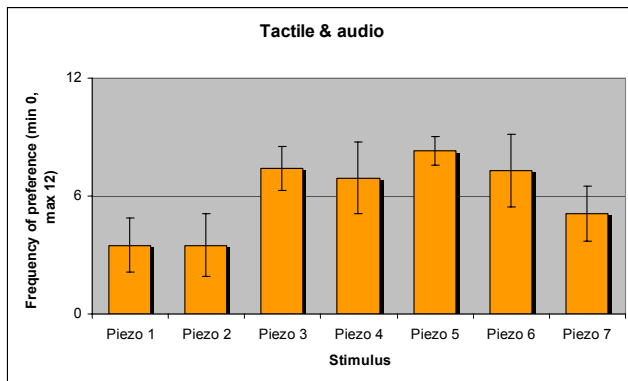
which constituted 21 different pairs. These 21 stimuli pairs were repeated two times in a randomized order resulting in a total of 42 stimuli pairs. In other words, a single feedback, e.g. stimulus 2, was compared twice with each of the six other stimuli. Accordingly, every stimulus was evaluated 12 times per user. Before starting the experiment, the users were given a moment to try out the different stimuli. In the actual test, the users could compare the buttons for as long as they wanted, and when they decided which one felt more pleasant they said the letter of the most pleasant feedback aloud to the test moderator. After the test, there was a short interview concerning the tactile feedback and the characteristics of the experienced pleasantness of the feedback.



**Figure 4. The screenshot of the experimental application displaying two virtual buttons, A and B, on the touch screen.**

### 4.3 Results

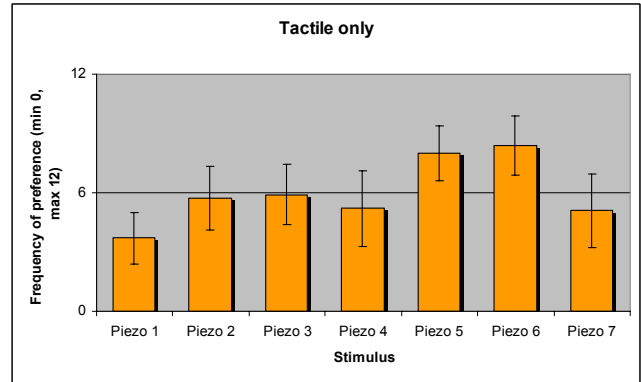
The mean values and 95% confidence intervals for subjective evaluations for the pleasantness of the different tactile and audio feedbacks can be seen in Figure 5. The results show that four feedbacks were evaluated as the most pleasant feedbacks and they are stimuli 3, 4, 5 and 6. Stimuli 1 and 2 were evaluated as the least pleasant feedbacks. The results showed that feedbacks 1 and 2 differ from feedbacks 3, 4, 5 and 6, in terms of statistical significance. Also feedback 5 differs from feedback 7 ( $p < 0.000$ ).



**Figure 5. Subjective evaluations of different tactile & audio stimuli pleasantness.**

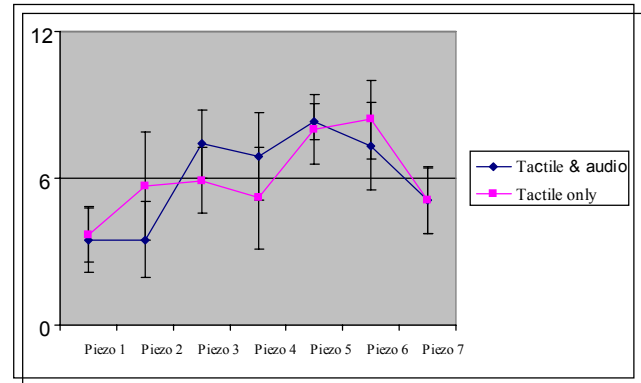
The Figure 6 shows the mean values and 95% confidence intervals for subjective evaluations for the pleasantness of the

different stimuli for tactile only feedbacks. The results show that feedbacks 5 and 6 were the most popular according to the users' evaluations of the pleasantness of the feedbacks. The results showed that feedbacks 5 and 6 differ from feedbacks 1, 4 and 7 in terms of statistical significance ( $p < 0.007$ ).



**Figure 6. Subjective evaluations of the feedback pleasantness for different tactile only feedbacks.**

A T-test showed that there were no statistically significant differences in the pleasantness evaluations between the two different parts of the experiment ( $p < 0.132$ ). Although the differences visible in the Figure 7 were not statistically significant, the audio appears to have some effect on the subjectively perceived pleasantness of the tactile stimulus.



**Figure 7. The pairwise comparisons between two conditions.**

### 4.4 Conclusions

In this study it was noticed that the feedbacks generated with 46 mA current were perceived most pleasant compared to the other feedbacks. There were altogether three such feedbacks (Piezo 3, Piezo 5, and Piezo 6) in the study that were perceived the same in terms of pleasantness, but only varied in terms of the perceived intensity, and generally they all were evaluated more pleasant than the other feedbacks.

There were no statistical differences between the tactile & audio and tactile only conditions. However, the results suggest that the audio feedback could impact the subjectively perceived pleasantness of the tactile feedback in a way that perceived pleasantness is reduced, especially when the audio feedback is loud. This was predictable, since in the previous intensity studies [12] the audio feedback was noticed to bias the tactile feedback intensity evaluations in a way that stimuli which have higher



sound levels were biased more than stimuli that have lower sound levels. However, the conditions between the intensity study [12] and the current study were different, as in the intensity study the audio feedback was totally excluded, but in the current study the audio feedback was masked with random street noise. There were also observable differences in stimulus evaluations between the subjects. From the results of the interview it was noticed that some of the subjects preferred stronger stimuli while some of the subjects liked the weaker ones. Also, some subjects preferred the sharp and strong stimuli when the audio feedback was masked, but did not like them at all when both tactile and audio feedbacks were present. This implies that different people in general and even an individual in different contexts can have a distinctive taste for tactile feedback. Therefore, it is suggested that the feedback intensity should be customizable, for example by using three intensity levels.

## 5. EXPERIMENT 2: VIBRATION MOTOR

The second experiment investigated the subjective perceived pleasantness of different tactile feedbacks for a virtual button in a vibrotactile enhanced touch screen.

### 5.1 Stimuli

To create different sets of vibrotactile stimuli, the drive time parameter was manipulated. Using drive times in the range of 10 ms to 24 ms, six different vibrotactile stimuli were created. This drive time range was chosen after empirical studies. They indicated that when the drive time was less than 10 ms, the feedback was far too weak, and when the drive time was over 24 ms, the feedback was uncomfortably strong. Physical properties of the stimuli comparable to the ones in Experiment 1 are shown in Table 2. It should be noted that the audio signal levels are not significant perception-wise in this experiment, since they are under or very close to the levels in the silent office room used for the experiment. The tactile feedback was presented only when the button was pressed.

Table 2. Stimuli parameter values for Experiment 2.

Stimulus	Drive time (ms)	Measured duration (ms)	Maximum Displacement ( $\mu\text{m}$ )	Audio volume (dB)
Vibra 1	10	4	4	<35
Vibra 2	13	6	8	<35
Vibra 3	16	9	12	<35
Vibra 4	19	12	30	<35
Vibra 5	21	14	35	37
Vibra 6	24	16	35	37

### 5.2 Methodology

Ten participants, nine males and one female, all employees of Nokia Research Center, and different from the first experiment, took part in the study. The age of the participants varied from 23 to 44 years, average age being 28 years. All the test users were right-handed and they all used their right hand thumb to press the virtual buttons on the touch screen. None of the test users had earlier experience with tactile feedback on touch screen. The experiment was conducted in an office room where test users sat in silence when using the touch screen device. The touch screen again displayed two virtual buttons, A and B (Figure 4), which gave tactile feedback when pressed. Visual stimuli were identical

to the ones used in Experiment 1. Altogether 6 different physical stimuli were tested with a pairwise comparison method, which resulted in 15 different pairs. These 15 stimuli pairs were repeated three times in a randomized order resulting to a total of 45 stimuli pairs. A single feedback, e.g. stimulus 2, was compared pairwise three times with each of the five other stimuli. Accordingly, every stimulus was evaluated 15 times per user. Before starting the experiment users were given a moment to try out the different stimuli. In the actual test the users could compare the buttons for as long as they wanted and when they decided which one felt more pleasant they said the letter for the more pleasant one.

### 5.3 Results

The mean values and 95% confidence intervals for subjective evaluations for the pleasantness of the different tactile feedbacks are presented in Figure 8. From the figure it can be seen that there is a clear trend that the stimuli in the mid range of drive times are more preferred. The results showed that stimulus 1 differs from stimuli 3 and 4, and stimulus 6 differs from stimuli 2, 3, and 4 in terms of statistical significance ( $p < 0.004$ ).

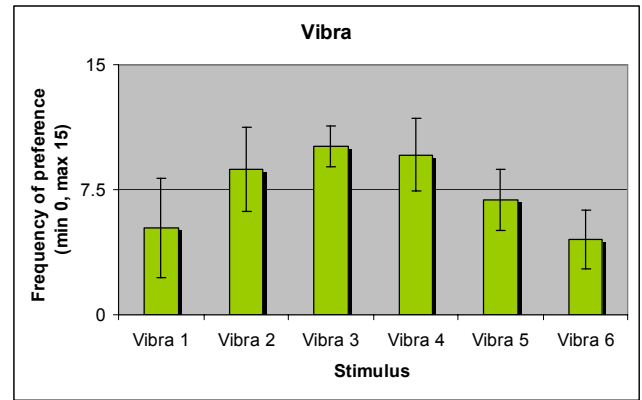


Figure 8. Evaluations of the feedback pleasantness for different vibra feedbacks.

### 5.4 Conclusions

It was found in the Experiment 2 that the vibra feedbacks generated with 13, 16, and 19 ms drive time, respectively, were perceived most pleasant compared to the other feedbacks. The feedback generated with 16 ms drive time was rated slightly more pleasant than the other two feedbacks and the evaluations had less variance. Therefore it is suggested that the 16 ms feedback should be considered when using vibration motor as a tactile feedback technology in touch screen devices. This result cannot be directly generalized to all touch screen devices because different physical device characteristics have an impact on the optimum feedback parameters. However, this result can be considered indicative for other touch screen devices.

## 6. EXPERIMENT 3: COMPARISON

This experiment compared the two most pleasant touch screen virtual button tactile feedbacks found in the first two experiments in addition to non-tactile condition in terms of usability in a realistic task. The task was based on standard number entry with a numeric keypad.

## 6.1 Stimuli

For this experiment the piezo and vibra stimuli were chosen according to the previous pleasantness study results meaning that the chosen ones were the stimuli Piezo 5 and Vibra 3, evaluated as the most pleasant piezo and vibra feedback by the test users.

**Table 3. Stimuli parameter values for Experiment 3.**

<i>Stimulus</i>	<i>Drive current (mA)</i>	<i>Total Duration (ms)</i>	<i>Maximum Displacement (<math>\mu\text{m}</math>)</i>	<i>Audio volume [dB]</i>
Piezo (Piezo 5)	46	13	105	46
<i>Stimulus</i>	<i>Drive time (ms)</i>	<i>Total Duration (ms)</i>	<i>Maximum Displacement (<math>\mu\text{m}</math>)</i>	<i>Audio volume [dB]</i>
Vibra (Vibra 3)	16	9	12	<35

In the no tactile feedback condition there was no active tactile feedback, only the natural sensation when the touch-sensitive screen surface is touched.

## 6.2 Methodology

Altogether twelve participants, all different from the first two experiments, took part in the study. There were seven males and five females participating, all employees of Nokia Research Center. The age of the participants varied from 21 years to 49 years, the average age being 30 years. Nine of the test users were right-handed and they used their right hand thumb to press the virtual buttons on the touch screen. The other three were left-handed and they used their left hand thumb respectively. None of the test users had earlier experience with tactile feedback on touch screen. The test was conducted in an office room, where the test users sat in silence while using the touch screen device. The test consisted of three conditions: one with piezo feedback, one with vibra feedback and one without tactile feedback.

The experimental software application showed a virtual number keypad, buttons 12x9 mm in size with 1 mm space between them, and three numbers on the touch screen. The task was to key in the three numbers with the virtual keypad. The numbers appeared on the screen and disappeared once the user started to key them in. The users concluded every three digit entry task by pressing the #-button (Figure 9). There were altogether 55 different three digit number series in one test. A within subjects design was used where all participants completed the tasks in all conditions. The test order was fully randomized and counterbalanced. The experimental software application measured the time from the first key press to the key press of the #-mark and it also wrote the numbers the test user entered into a results file. Before starting each test case, there was a short rehearsal where test users could try to key in a few three digit number series. After completing the tasks, participants completed a short questionnaire and interview. Users were asked to rate their degree of agreement with the following statements using a 1-7 Likert scale, where 1 meant totally disagree and 7 totally agree:

- This keypad is pleasant to use.
- I felt myself comfortable when using this keypad.
- Pressing the keypad buttons felt just like pressing physical ("real") buttons.

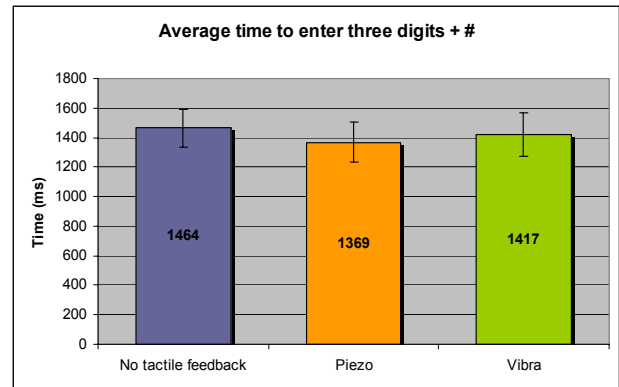
- I always knew that the device received my key press.
- I would like to buy a device with this kind of keypad.



**Figure 9. Experimental software screenshot: three numbers appeared on the display at once and user's task was to key in these numbers and press #-mark using the virtual keypad.**

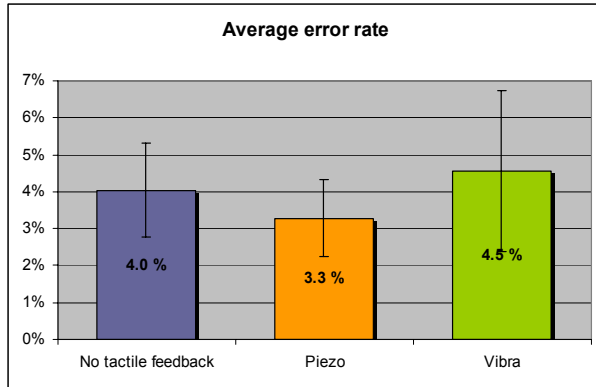
## 6.3 Results

Figure 10 shows the mean values and 95% confidence intervals for the time to enter three digits and the hash (#) mark in milliseconds with different tactile feedbacks. The results showed that the keypad with piezo feedback was the fastest to use. The task took 4% longer on the keypad with vibra feedback and 7% longer on the keypad without tactile feedback, however the results are not statistically significant ( $p < 0.076$ ).



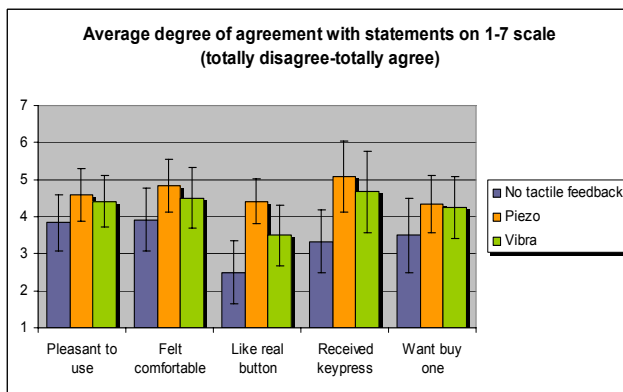
**Figure 10. Mean values and 95% confidence intervals for time (ms) to enter three digits and hash (#) mark.**

The Figure 11 shows the mean values and 95% confidence intervals for error rates with different tactile feedbacks. The results show that the least errors occurred with the keypad with piezo feedback. With the keypad with vibra feedback and the keypad without tactile feedback, the average error rate grew by 38% and 23% respectively, however the results are not statistically significant ( $p < 0.979$ ). It should be noted that due to prototype unreliability some errors were constantly recorded in all feedback conditions even though the user pressed correctly. Therefore, zero error values were impossible to obtain with the test equipment.



**Figure 11. Mean values and 95% confidence intervals for average error rate.**

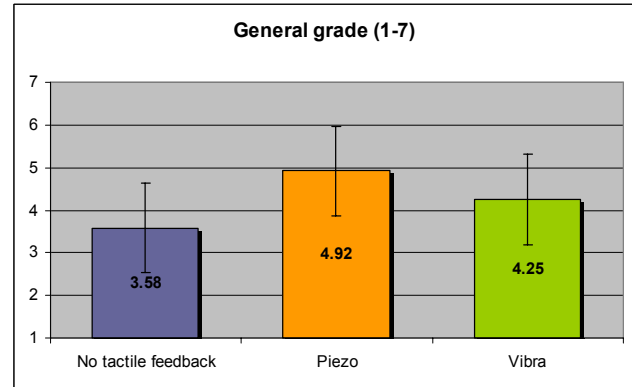
Figure 12 shows the mean values and 95% confidence intervals for the degree of agreement with the statements on a 1 to 7 (totally disagree to totally agree) scale. The results show that the keypads with piezo and vibra feedback were rated higher than the keypad without tactile feedback. Also the keypad with piezo feedback received slightly higher score in all five statements compared to the keypad with vibra feedback.



**Figure 12. Mean values for degree of agreement with statements on 1-7 scale.**

Figure 13 shows the mean values and 95% confidence intervals for general grade (on 1 to 7 scale) given by the test users. The results show that the keypad with piezo feedback was rated higher than the keypad without tactile feedback and the keypad with vibra feedback.

The results from the interview showed that on average, users preferred the keypad with piezo feedback compared to the keypad with vibra feedback and the keypad without tactile feedback, because it gave the most natural feeling of a real button. Vibra feedback was commented to be too strong, because it vibrated the whole device, but it was better than typing without any tactile feedback. A couple of users still preferred vibra feedback to piezo feedback.



**Figure 13. Mean values and 95% confidence intervals for the general preference rating on 1-7 scale.**

## 6.4 Conclusions

In this study it was found that a keypad with tactile feedback was more efficient and more pleasant to use than a keypad without tactile feedback in this use case. Therefore the results suggest that tactile feedback improves the usability when entering numbers with virtual buttons using fingers on a touch screen. The results also showed that the keypad with piezo feedback was slightly faster to use than the keypad with vibra feedback. Also the error rate was lowest with the keypad with piezo feedback. Results showed that the keypad with piezo feedback received the highest scores in the satisfaction questionnaire in all the five statements compared to the keypad with vibra feedback and the keypad without tactile feedback. Finally, the keypad with piezo feedback also received the highest score in the general preference grade given by the test users compared to the keypad with vibra feedback and the keypad without tactile feedback. Although the individual metrics did not show statistically significant differences in this study, it can be concluded that piezo is the preferred method for producing tactile feedback for finger-used virtual buttons. Vibra is slightly but consistently less preferred, while no tactile feedback is clearly the worst option. However, it is important to note that due to the variation in the results, a minority of users would prefer vibra or no tactile feedback.

## 7. OVERALL CONCLUSIONS

The results of these three experiments showed that people perceive some tactile feedbacks more pleasant than others when virtual buttons are pressed with fingers on a touch screen. This perceived pleasantness seems to depend on the characteristics of the tactile feedback parameters that define the wave shape of the stimuli. It was found that 46 mA drive current for piezo actuator, and 16 ms drive time for vibration motor create the most pleasant tactile feedbacks. These parameters cannot be directly generalized to all touch screen devices because the mechanical design of the device impacts the optimum feedback parameters. However, these parameters can be considered indicative for other touch screen devices.

The first two experiments here have proved that it is possible to modify the perceived characteristics of the virtual button tactile clicks in terms of pleasantness. The comparison experiment then confirmed the findings from earlier studies that tactile feedback is superior to a non-tactile condition when virtual buttons are used

with finger regardless of the technology behind the tactile feedback. The results also suggest that piezo feedback is the preferred method producing tactile feedback for virtual buttons, although the results are not statistically significant.

The results also showed that tactile feedback improves the usability of virtual buttons: it not only improves the user performance but it also leads to more satisfying user experience in touch screen interaction. That is not a surprise as people are used to feeling the shapes and textures of physical objects they are interacting with. If we take the sensation of touch away, it certainly will not improve the usability of mobile devices and at worst, the lack of tactile feedback can become a barrier for the interaction. To make touch screen interaction more natural, tactile feedback needs to be added so that the user is able to feel what he or she is interacting with.

Some of the findings highlighted the subjective nature of pleasantness ratings. Some users may prefer sharp and strong stimuli when there is no audio feedback present, but then find the same tactile feedback unpleasant when audio feedback is present. This implies that different users in general and even an individual in different contexts can have differing preferences in terms of tactile feedback. Therefore, it is suggested that the feedback should be customizable for the user and additional audio feedback should be optional; intrinsic audio feedback should be eliminated.

Altogether, the knowledge introduced in this work can help the designers to create better touch screen virtual buttons and keyboards.

## 8. DISCUSSIONS AND FUTURE STUDIES

Future studies will continue research on tactile feedback for virtual buttons. In current experiments we used piezo feedback both when the button was pressed and released, and the vibro-based tactile feedback was presented only when the button was pressed. This should be checked in future studies if it had any effect on the results. Other options for future studies are to have a better design space for vibro feedback as now we could design it only by altering the drive time. Another next step will be to do more formal studies of the effect of the intrinsic audio feedback from piezo actuator, as well as studies with audio controlled separately from the tactile modality. Also, none of the feedbacks in this work were given a top rating of 12 in terms of pleasantness indicating that some different clicks should be tried to see if they could reach the highest level of pleasantness.

The tactile feedback could also be used to communicate other information of the virtual buttons than just confirming presses, for example the texture and shape of the touch screen virtual buttons and the location of the buttons. One alternative could be to use distinct tactile feedback for different buttons so that the user could distinguish the buttons and controls on the screen based on the tactile sensation they provide. This could make touch screen mobile devices more accessible to visually impaired and blind people, as current touch screens without any tactile feedback are impossible for the visually impaired to use.

Tactile feedback could also be added to many other graphical user interface elements on a touch screen besides virtual buttons. For example, finger-used sliders and scrollbars could provide different kind of tactile feedback to inform the location of the element but also to provide other information like e.g. the state of the element. Future studies will examine the benefits of adding tactile feedback

to these other touch screen user interface elements when using a finger on the screen for interaction. Also, these tactile feedback designs have to be validated in terms of pleasantness.

## 9. ACKNOWLEDGMENTS

We would like to thank Jukka Jalkanen, Risto Suijala and Juhani Tuovinen for building the test equipment and software and helping with setting them up. We also want to thank Miika Silfverberg and Ville Tikka for their contribution to the current research.

## 10. REFERENCES

- [1] Samsung, "http://product.samsung.com/cgi-bin/nabc/mobile/wireless\_main.jsp," Samsung Corporation, 2008.
- [2] LG, "http://www.lgmobilephones.com," LG Corporation, 2008.
- [3] Immersion, "VibeTonz, http://www.immersion.com/mobility/touchscreen/vt-system.php," Immersion Inc., 2008.
- [4] I. Poupyrev and S. Maruyama, "Tactile interfaces for small touch screens," presented at UIST 2003, 2003.
- [5] J. C. Lee and e. al, "Haptic Pen: a Tactile Feedback Stylus for Touch Screens," presented at UIST'04, Santa Fe, NM, USA, 2004.
- [6] A. Nashel and S. Razzaque, "Tactile Virtual Buttons for Mobile Devices," presented at CHI2003, Ft. Lauderdale, Florida, USA, 2003.
- [7] M. Fukumoto and T. Sugimura, "Active Click: Tactile Feedback for Touch Panels," presented at CHI2001, 2001.
- [8] S. Brewster, F. Chohan, and L. Brown, "Tactile Feedback for Mobile Interactions," presented at CHI2007, 2007.
- [9] E. Hoggan, S. A. Brewster, and J. Johnston, "Investigating the Effectiveness of Tactile Feedback for Mobile Touchscreens," presented at CHI 2008, Florence, Italy, 2008.
- [10] I. Poupyrev, S. Maruyama, and J. Rekimoto, "Ambient Touch: Designing tactile interfaces for handheld devices," presented at UIST 2002, 2002.
- [11] J. Nielsen, *Usability Engineering*: MA: Academic Press, 1993.
- [12] V. Tikka and P. Laitinen, "Designing Haptic Feedback for Touch Display: Experimental Study of Perceived Intensity and Integration of Haptic and Audio," presented at Workshop on Haptic and Audio Interaction Design, Glasgow, Scotland, UK, 2006.
- [13] P. Laitinen and J. Mäenpää, "Enabling mobile haptic design: Piezoelectric actuator technology properties in hand held devices," presented at HAVE'06 (Haptic Audio Visual Environments), Ottawa, Canada, 2006.
- [14] L. Pesqueux and M. Rouaud, "Vibration level of mobile phones' silent alerts," in *Department of Acoustics*. Aalborg: Aalborg University, 2005, pp. 87.
- [15] E. Hoggan, T. Kaaresoja and P. Laitinen, "Cross-Modal Congruence: The Look, Feel and Sound of Touchscreen Widgets," will be presented in ICM2008, Crete, Greece, 2008.