Haptic Numbers: Three Haptic Representation Models for Numbers on a Touch Screen Phone

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ABSTRACT
Systematic research on haptic stimuli is needed to create viable haptic feeling for user interface elements. There has been a lot of research with haptic user interface prototypes, but much less with haptic stimulus design. In this study we compared three haptic representation models with two representation rates for the numbers used in the phone number keypad layout. Haptic representations for the numbers were derived from *Arabic* and *Roman* numbers, and from the *Location* of the number button in the layout grid. Using a Nokia 5800 Express Music phone participants entered phone numbers blindly in the phone. The speed, error rate, and subjective experiences were recorded. The results showed that the model had no effect to the measured performance, but subjective experiences were affected. The Arabic numbers with slower speed were preferred most. Thus, subjectively the performance was rated as better, even though objective measures showed no differences.

Categories and Subject Descriptors
H.5.2 [**Information Interfaces and Presentation**]: User Interfaces – *Evaluation/methodology, Haptic I/O.*

General Terms
Performance, Design, Experimentation, Human Factors.

Keywords
Haptic feedback, User interfaces, Design, Mobile user.

1. INTRODUCTION
In the current state of the haptics research, there is a lack of information about how to design haptic cues for the components used in the user interfaces as well as how to represent GUI primitives and information haptically. However, in the research on haptic user interfaces (HUI) corresponding to graphical user interfaces the design problems should be taken into account [11]. With an attractive design people tend to value the usability of the device, even more than with more efficient but less attractive device [9].

In this study, we compared three designs with two representation rates for creating haptic cues to represent numbers on a touch screen device. The aims of this study were to compare three different approaches to define haptic descriptions for the numbers, to compare the effect of the representation models of haptic numbers to user performance and satisfaction, and to find out which representation model would be the best for the users.

Improvement in the virtual keyboard writing tasks [1][5] supports the interpretation that haptics could be applicable for number entry tasks. There is some research regarding which parameters can be used for creating recognizable haptic stimuli. In the recognition of tactile stimuli the best parameters were rhythm, spatial location [3] and waveform modulation [4][6] as compared to speed of the moving stimulus [6], amplitude [4][6], duration [6], and frequency [4]. Amplitude was the best parameter for representing size [2].

Also primitives of the components have been built with promising results. For example, similar to our experiment, the buttons have been haptically enhanced with a "Pop" when entering in the button, with vibration on the button, and with a pulse when leaving the button [7]. Haptic design models for describing the button edges have been studied earlier [8]. Similar approach for representing number keys, as in the current study with location based coding, has been used with a prototype device with several actuators [12]. A successful implementation of Braille characters with similar rhythm based coding [10] supported the approach to represent numbers with rhythm based haptic representation based on existing literal number coding.

Even though several proof of concept prototypes with haptically enhanced graphical user interface elements have been built, and some research for haptic modeling of user interface primitives exists, there is still need for research with systematic approach for finding out how to design haptic counterparts for the graphical primitives and how different haptic parameters affect user impression of those haptic primitives.

The present aim was on haptic number representation. Three promising approaches for haptic design were selected. Their stimulus parameters were systematically varied to to find out which designs was the most applicable for representing numbers.

2. EXPERIMENT
2.1 Participants
24 voluntary participants (7 female and 17 male) participated in the experiment (mean age 31 years, range 20-54 years). 21 of the participants were right-handed by their own report. In the experiment three participants used their non-dominant hand, because they were used to use that with mobile phones.

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2.2 Apparatus and Software

The haptic device used was a Nokia 5800 Express Music phone with a resistive touch screen. The phone's rotation motor actuator was used to generate haptic feedback with the QT software built for the experiment. The used software had a standard phone keypad layout, with number keys only (Figure 1). The software was developed using QT for Symbian 4.6.0 with Mobile Extension Preview 2 for the vibrating motor control.

Figure 1: Software

In the software some haptic primitives were provided for making it easier to find and use the touch screen buttons. The haptic stimuli representing graphical primitives of the buttons were the same in all the number representations. Haptic information was provided for participants with a texture while moving the finger on the button to inform, if they were over a button or not. For the edges of the buttons haptic feedback was different while moving over the edge towards the button and while moving out of the button. These edge primitives were adapted from known design paradigms for the haptic edges [8]. When a button was pressed down, a "click" down was repeated and while releasing a button there was haptic representation for the rising button, which also told the participant that a number was selected. Representation for the number attached to the button was provided with 500 ms delay, after the participant's finger had entered the button. Parameters of individual primitives can be found in Table 1.

2.3 Stimuli

There were three representation models for the numbers. These representation models were based on *Arabic* numbers, *Roman* numbers and the *Location* of the number key in the keypad grid. With all the models, number 0 in the keypad was represented with number 10. All the models were experimented with two presentation speeds: *Fast* with 100 ms as basic pause time between the individual pulses and *Slow* with 200 ms basic pause time. Parameters are the proportional power input to the rotation motor actuator in percentage, the direction the motor is driven, the power input time to the motor and the pause between separate haptic pulses provided. Parameters can be found in Table 1.

The stimuli in the Arabic representation were combined from identical haptic pulses, with as many pulses as the number indicated, except for the number zero that had ten pulses. Pulses were grouped so that with larger numbers than five the pause between fifth and sixth pulses was twice as long as within other pulses.

The stimuli in the Roman representation were combined from three different haptic pulses, where the weakest pulse represented I, the strongest X and the middle one V. Numbers were combined from these digits as ordinary roman numbers, except for number zero which was presented with X. The pause was twice longer between different digits; *i.e.* between I and V.

The stimuli in the Location representation were combined from four different haptic pulses. The length and the amplitude of the pulse represented the row number in the keypad grid where the button was located. The weakest pulse marked the topmost row with numbers one to three and the strongest pulse marked the lowest row with the number zero. The amplitude and the length of the pulses grew with even steps from top to down. The number of the pulses was the same as the position of the button in the row from left to right *i.e.* one to three pulses.

Table 1: Haptic parameters. (P) Proportional power, (rd) rotation direction, (t) rotation time and pause between pulses.

Roman	P (%)	rd	t (ms)	Pause (ms)	P (%)	rd	t (ms)
I	5	↑	50	-	-	-	-
V	100	↑	100	-	-	-	-
X	100	↑	200	-	-	-	-
Arabic							
1 pulse	100	↑	50	-	-	-	-
Location							
Row 1	25	↑	50	-	-	-	-
Row 2	50	↑	100	-	-	-	-
Row 3	75	↑	150	-	-	-	-
Row 4	100	↑	200	-	-	-	-
Primitives							
Edge in	100	↑	35	10	100	↓	25
Edge out	100	↑	35	-	-	-	-
Texture	5	↑	2	-	-	-	-
Pushdown	100	↑	35	50	100	↓	25
Release	100	↑	50	10	100	↓	25

2.4 Procedure

The task for the participants was to enter phone numbers with the phone blindly. During number entry the selection times for each individual number and selected number were recorded. After each model the participants rated the model with the following three nine point bi-polar scales: "How well you recognized the numbers?", "How pleasant the representation was?", and "How difficult the numbers were to understand?". In the scale value -4 was did not recognize at all, very unpleasant and very difficult, and value 4 was perfectly, very pleasant and very easy.

Before the experiment each participant was allowed to explore all the representation models with both speeds to learn how numbers were represented. The participants were instructed to perform as accurately as possible, but still as fast as they could. The accuracy was emphasized. In the actual experiment participants' vision was blocked using a box where the entry hand was in it with the phone. Hearing was blocked with pink noise played through a hearing protector headset. The participants used the phone with their thumb.

The presentation order of the numbers was counter-balanced between the conditions and condition order between the participants. There were seven 7-digit phone numbers in the experiment, excluding operator code 050, which was at the beginning of all numbers. This was to initialize participant's finger to middle line of the phone and have everyone's finger in the same position at task start. Thus, in total there were 7*7=49 numbers in each condition which were taken in the analysis. The numbers were balanced so that the phone numbers did not include any number twice and all numbers were presented equally, except 0 which had one occurrence less.

2.5 Data Analysis

Users had difficulties to blindly press the screen with the required amount of pressure for error-free detection for the resistive touch screen. This caused random input, when a participant moved the finger on the screen touching lightly and the phone received the input randomly as touching or not touching. This caused some errors in the data which were recognized and processed manually.

Data was processed manually with following method. Data from each task segment was first split to individual phone numbers. This could be done by recognizing initial strings (050), which were not taken into analysis. Each phone number was processed and accidental double entries and extra numbers on the path from one number to another were taken out. After that, correct number sequences were manually recognized. If there was doubt whether the input was correct or not, it was interpreted as an error. Thus, the effect to the result was raising the error percentage. The missing values (input missing from requested phone numbers) were not calculated to the error percentage. They were analyzed separately to ensure that there was no difference between conditions in missing values, which could have then affected the results and the comparison of the conditions. Selection times were calculated from the time spent between individual number entries.

Within-subjects repeated measures analysis of variance (ANOVA) was used for statistical analysis. If the sphericity assumption of the data was violated, Greenhouse-Geisser corrected degrees of freedom were used to validate the F statistic. Bonferroni corrected pairwise t-tests were used for post hoc tests.

3. RESULTS

Means and standard error of the means (S.E.M.s) for all the results are presented in Figure 2. For the ratings of the subjectively estimated stimulus recognition rate, a 2 × 3 two-way (speed × number presentation style) ANOVA showed a statistically significant main effect of number presentation style ($F(2, 46) = 9.9$, $p < 0.001$). Post hoc pairwise comparisons showed that the participants rated the Arabic number presentation style as more recognizable than the Roman ($MD = 1.0$, $p < 0.05$) or the Location based ($MD = 1.8$, $p < 0.001$) number presentation styles.

For the ratings of the pleasantness, a 2 × 3 two-way (speed × number presentation style) ANOVA showed a statistically significant main effect of speed ($F(2, 46) = 4.7$, $p < 0.05$) and number presentation style ($F(2, 46) = 6.7$, $p < 0.01$). Post hoc pairwise comparisons showed that the participants rated numbers presented slowly as statistically significantly more pleasant than numbers presented quickly ($MD = 0.6$, $p < 0.05$). Post hoc pairwise comparisons also showed that the participants rated the Arabic number presentation style as more pleasant than the Location based ($MD = 1.5$, $p < 0.01$) number presentation styles.

For the ratings of the difficultness, a 2 × 3 two-way (speed × number presentation style) ANOVA showed a statistically significant main effect of number presentation style ($F(2, 46) = 8.1$, $p < 0.001$). Post hoc pairwise comparisons showed that the participants rated the Arabic number presentation style as easier than the Roman ($MD = 1.1$, $p < 0.05$) or the Location based ($MD = 1.7$, $p < 0.001$) number presentation styles.

4. DISCUSSION AND FUTURE WORK

We developed a fully haptic number keypad making use of the limited haptic capabilities available in the phones today. We were able to recreate similar haptic edge effects with a consumer model phone, as done in an earlier work with a prototype device [8] by transforming input parameters for piezo electric actuators applicable for rotation motor actuator. By using the number representation models actuated with a single rotation motor actuator, we were able to create haptic number entry solutions based on existing mental representations for the numbers. Using these models we achieved smaller error rates with a single actuator and around the same error rates than in an earlier solution making use of multiple actuators [12].

Interestingly, the comparison of the models of haptic number representations did not reveal any significant differences in the measured performance, but still it had an effect in the subjective evaluation and the user's experience of how well the task was performed. Thus, even if the measured performance does not support the issue that any of the models would be better than another, subjective ratings suggest that the most familiar Arabic number model with the slower speed would be better for real applications. Also, when it is known that with an attractive design people tend to value usability of the device over performance only [9], subjective ratings should be taken into account in the design.

Our results support the earlier research where it has been shown that existing literal coding, like Braille [10] can be represented with haptics. Also, our results support the results reported earlier that in the recognition of tactile stimuli, rhythm [3] and waveform modulation [4][6] would be good parameters.

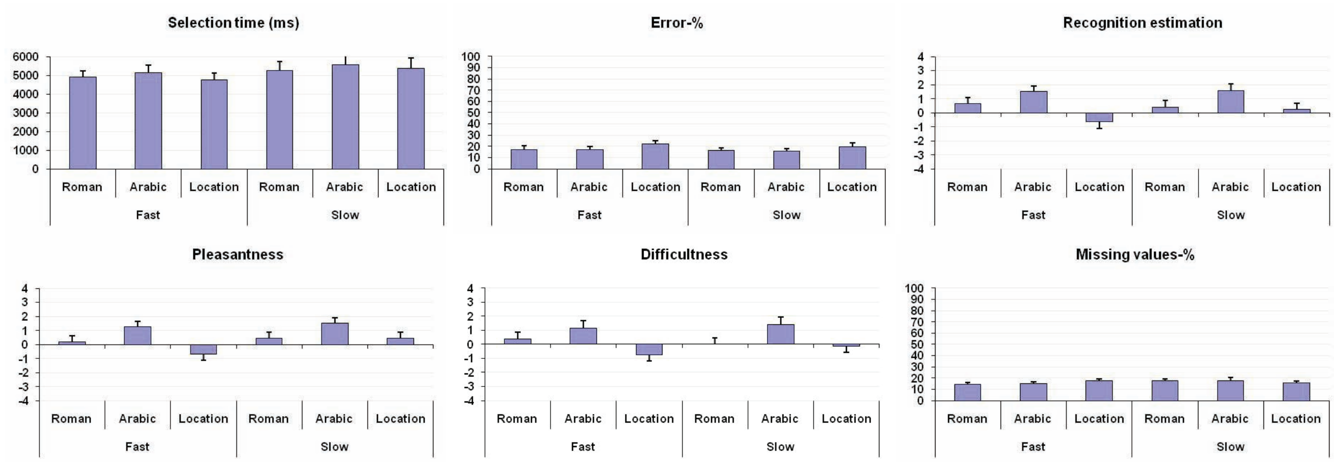

Figure 2: From top left to bottom right: Selection times (ms) for individual numbers. Error-% of the number typing. Subjective estimation of the recognition rate. Subjective rating of pleasantness. Subjective rating of difficultness. Missing entries in the data.

Quite high error rate and slow input rate reveal that pure touch based task was demanding. This was also supported by comments of the participants after the experiment. Also, the phone numbers given for users were unfamiliar to them, which made the task harder. Error rate and input speed might be better, if the numbers were shorter and more familiar to the users and if vision would be part of interaction as a supportive modality. As there was no learning phase and novice users were the participants of the study it could be argued that with an appropriate learning time, users would be much more confident with touch interaction and thus, error rate and speed would improve in long-term usage.

Based on the current results, complete blind usage scenarios cannot be recommended for long and unfamiliar numbers. However, using shorter and already known numbers it might be easier to enter them and, thus, they would be more applicable. Also, the problems arose from difficulties to use touch screen with appropriate pressure. This is due to the case that software responded to the touch events, and based on those events, provided haptic feedback. With a weak touch pressure, all the haptic feedback designed to be presented might not have been presented and thus feedback been more confusing, which could have raised the input time and error rate.

5. CONCLUSIONS

Even though the objective performance was not affected by parameters used in the experiment, the users preferred the most familiar Arabic numbers represented with the slower speed. Thus, when representing numbers with haptics, a better choice would be to use the slow Arabic number based rhythmic representation. Based on our experiences, we would recommend interaction schemes that allow at least partial use of sight and use of highly responsive touch screen, where the amount of the pressure required is minimal.

6. ACKNOWLEDGMENTS

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