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Understanding Users' Perception of Simultaneous Tactile Textures

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ABSTRACT

We study users' perception of simultaneous tactile textures in ultrasonic devices. We investigate how relevant is providing the user with different complementary and simultaneous textures with respect to the different fingers that can be used to touch the surface. We show through a controlled experiment that users are able to distinguish the number of different textures independently of using fingers from one or two hands. However, our findings indicate that users are not able to differentiate between two different textures, that is to correctly identify each of them, when using fingers from the same hand. Based on our findings, we are then able to outline three relevant guidelines to assist multi-finger tactile feedback ergonomic and devices design.

Author Keywords

Tactile feedback; perception simultaneous textures; ultrasonic device; experiment; finger; one-handed; two-handed.

ACM Classification Keywords

H.5.2. Information Interfaces and Presentation (e.g. HCI): User Interfaces

INTRODUCTION

Touch interaction is one of the most dominant ways users interact due to the broad range of interaction styles offered by multi-touch devices, but also to the pervasiveness of touch-enabled devices. Touch interaction can be enhanced with a tactile feedback that provides stimulation when touching the surface with the subsequent aim of integration in the mobile world. For example, electrovibration technologies [2, 14] enhances the friction between the finger and the interaction surface while ultrasonic technologies reduce the friction through the "squeeze film effect" [1, 3, 10, 15]). In the remainder of this paper, we are specifically interested in the latter type.

The current practice of tactile feedback surface design has outlined several guidelines to assist practitioners in how users feel and identify objects through the touch sense [11, 8, 13].

Different applications have then been emerged to improve the immersive experience during interaction [9]; or to offer accessible interaction design for people with impairment [6]; or to strengthen the interaction [10]. However, and despite this positive evolution, tactile feedback interaction with most current devices is still limited to a one unique tactile feedback for the whole device. In fact, touching the surface with one finger or multiple fingers is still implemented to provide the same feedback for the users even when fingers are touching different textures (e.g., the index finger is touching the sea while the middle finger is touching the sand), or when different commands are attributed to different fingers or chords in contact with the surface [5]. This can be explained by today's lack of hardware capability of providing different simultaneous tactile textures. We also believe that the community lacks an in-depth understanding of users' perception of simultaneous tactile textures. Among other fundamental questions, one can for instance ask the following: are users able to perceive simultaneous but different textures on different fingers? Are users able to identify different textures when using fingers from the same hand? Does the number of hands matters in such a setting?

In this context, we argue that users' perception of simultaneous textures is an important factor for tactile feedback surface design that has been little explored so far and, consequently, is little understood. Two limited studies addressing similar challenges have been conducted for braille [16] and vibrotactile [4] devices. Ziat et al [16] evaluated whether participants are able to identify dots displacements and Catala et al. [4] asked participants to determine the location of a single object within the exploration area. In these both studies, the ability of users to identify simultaneous but different textures; each one sensed by a different finger in contact with the surface, has not been evaluated. Additionally, the findings there-in, although of valuable contribution, can not be mindlessly applied to ultrasonic devices which, in contrast to braille and vibrotactile devices, provide considerably different sensations [15]. Besides, vibrotactile devices suffer from a decrease in perception accuracy when sliding repeatedly [7]. In this paper, we examine users' perception of a pair of textures in ultrasonic devices, and we provide the community with the first investigations on the subject and the potential implications in terms of tactile feedback ergonomic and devices design.

The contributions of this work are: (1) through a controlled experiment, we deliver a comprehensive comparison between the use of different finger(s) conditions to perceive a pair of

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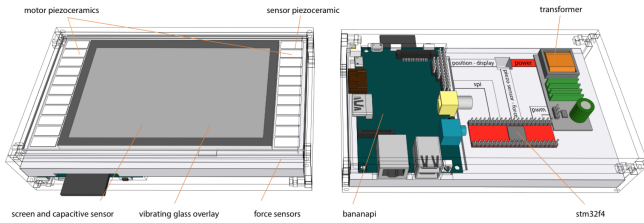


Figure 1: The E-vita device.

textures, (2) we report novel findings on user perception of simultaneous textures, mainly by showing that although users can distinguish *the number* of different textures, they are not able to correctly identify them when using only one hand, and (3) we derive three guidelines for multi-finger tactile feedback ergonomic and devices design.

EXPERIMENT

We conducted an experiment to evaluate whether simultaneous textures are consistently perceived by users. We are mainly interested in evaluating whether users are able or not to perceive simultaneous but different textures; each one is sensed by a different finger touching the surface. Moreover, we are interested in evaluating whether the user perception of simultaneous textures can be related to the number of hands touching the surface.

Participants

15 participants (3 females) volunteered to take part into our experiment. Their age was between 20 and 34 years (mean=26.35, s.d=3.67). All participants were right handed.

Method

Providing simultaneous but different tactile feedback embedded in the same surface is not available yet. We, therefore, limit the experiment to two textures. The rationale is that if no effect was found with this setting, it would be likely that no such effect exists in more complicated settings. We then, set-up two simultaneous tactile feedback surfaces (*E-vita* [15]); one used as a server while the second is used as a client; that together allow us to deliver two fingertip tactile feedback; each one is provided by a different surface.

The E-VITA device [15] (Figure 1) is based on a banana pi (Shenzhen LeMaker Technology Co. Ltd, China) single board computer featuring a 1 GHz ARM Cortex-A7 dual-core CPU with 1 GB of ram working in parallel. It is equipped with a 5 inches LCD display including a cheap capacitive sensor which allows a sampling frequency of 50 Hz, similar to the capabilities of commercial mobile devices.

On top of the display, a $154 \times 81 \times 1.6$ mm glass plate, resonating at 60750 Hz with a half wavelength of 8 mm, is fixed and actuated by twenty $14 \times 6 \times 0.5$ mm piezoelectric cells. A power electronic circuit converts a 12V DC voltage source into an AC voltage, controlled in amplitude and frequency and supplied to the piezoelectric cells. A microcontroller (stm32f4, STMicroelectronics, France) runs in parallel with the banana pi and adjusts the circuit's control signals in order to obtain the required vibration amplitude of the plate. For that purpose,

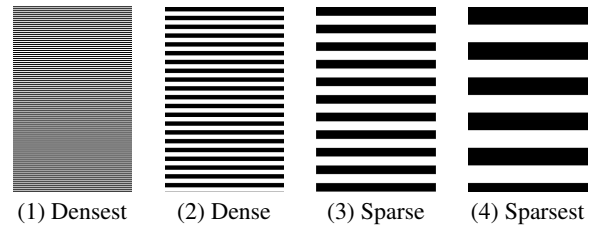


Figure 2: The four visual representation of the experimented textures numbered from left to right (1-4)

two additional piezoelectric cells are used as vibration sensors, and the vibration amplitude is controlled in a closed loop by the microcontroller. The reference value is sent by the banana pi to the microcontroller through a Serial Peripheral Interface (SPI) connection.

In this work, a texture (see Figure 2) refers to a sequence of periodic tactile feedback [13] such that the period to be reproduced inside the texture can be formed by some specific signal (periodic, structured noise, micro-geometry extracted, etc.). We then consider four different tactile textures. We encode the different textures with respect to different texture densities by considering the following spatial periodicity: *Densest* – 1.2 mm; *Dense* – 5 mm; *Sparse* – 10 mm and *Sparsest* – 20 mm (see Figure 2). High friction was associated to black color and low friction was associated to white color. The set of considered textures follows the set used by Rekek et al. [13]; for which users are shown to be able to distinguish them independently on the finger velocity; as well as current studies on user perception of tactile textures (e.g., [15, 8, 12]). The set of considered textures is also limited to one-dimensional textures in order to simplify the task.

To render a given texture we use the so-called Localized Haptic Texture (LHT) rendering technique [13]. LHT separates the tactile rendering in two different processes: first, the finger position is retrieved from the hardware, and the corresponding texture is selected through a search in a grid of taxels (tactile element). The taxel texture is then rendered locally by defining only one period of the texture and then repeated it in a loop at a rate that depends on finger's velocity. LHT was shown to provide a high-fidelity between the tactile texture and its visual representation. For instance, LHT leads to the highest level of quality of tactile rendering for both dense and sparse textures. In addition, the performance benefits of LHT were consistent across different finger velocities.

Design

A within-subjects design was used. The independent variables were the finger or chord used to *contact* the surfaces and the pair of *textures* to identify. We employ the same *contact* conditions than Ziat et al [16] and Catala et al. [4]. *Contact* covered then a specific *finger* (the index finger from the dominant hand), *one-handed* chord (index and middle fingers from the dominant hand) and *two-handed* chord (the two index fingers). The rationale of comparing the one finger condition to the chord conditions is to consider the finger condition as the baseline of what textures could be distinguished when using

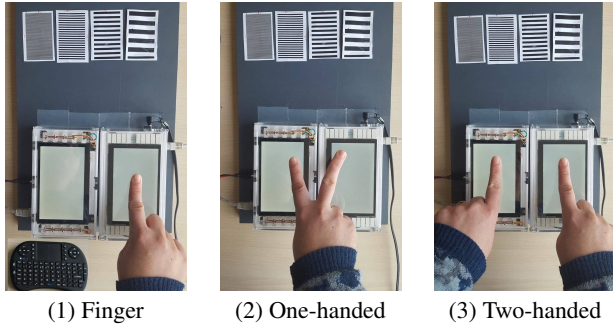


Figure 3: Set-up for the three *contact* conditions.

one finger sequential exploration of the pair of textures. The experiment was, also, limited to these three *contact* conditions in order to reduce the duration of the experiment. We consider all the ordered pairs of the four textures aforementioned (see Figure 2), where each texture is displayed on one different surface, hence investigating 16 pair of *textures* (12 pairs of different textures and 4 pairs of similar ones).

Task

The task required participants to use a specific finger or chord to *contact* the surfaces. Participants were then asked to move their finger(s) on the two surfaces from top to bottom and inversely to perceive the pair of textures, without a starting finger position or time restrictions. In the *finger* condition, participants were asked to move their index finger from the dominant hand on the first surface than on the second surface and so on (see Figure 3.1). Participants had the total liberty in choosing the surface they sensed first as well as how to proceed to explore the whole texture. In the *one-handed* condition, participants were asked to move simultaneously and similarly (the same movement direction and velocity) the index and middle fingers from the dominant hand such that the index finger explores the left surface while the middle finger explores the right surface (see Figure 3.2). In the *two-handed* condition, participants were asked to move simultaneously and similarly their index fingers such that the index finger from the right hand explores the right surface while the index finger from the left hand explores the left surface (see Figure 3.3). A trial ended once the participant press on the “enter” button on the external keyboard. The participants were then asked the following questions: (1) “Did you perceive the same texture on the two surfaces or two different textures”; (2) “I felt confident in my ability to determine the number of textures”; (3) “Please identify the two perceived textures, left texture then right texture” and (4) “I felt confident in my ability to identify the visual representation of the two textures”. Both confidence scales solicited ordinal responses from 1 = strongly disagree to 10 = strongly agree.

No visual feedback was shown on the surfaces, only tactile feedback was sent to the participant. However, four sheets of paper illustrating the visual of the four tactile textures were given to participants (see Figure 3). Each visual is given a number between 1 and 4. In addition, as the Evita device makes noise when alternating high and low frictions, the par-

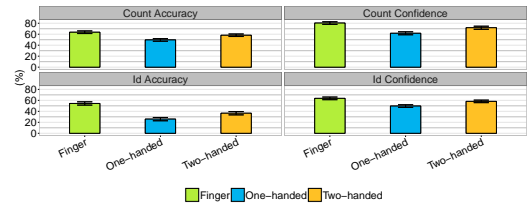


Figure 4: Mean (s.d) of the dependent variables (count accuracy and id accuracy) and the percentage of the confidence responses.

participants were equipped with noise reduction headphones to avoid any bias. Tactile feedback was hence made eyes-free since the participants were not able to see any visual (nor to hear any audio) rendering on the surface.

Procedure

After answering a demographic questionnaire, the experiment task was explained along with the additional requirement of using a specific finger or two-finger chord. The participant then began the experiment. The experimental trials were administered as 3 blocks of 48 trials, each block sharing a *contact* condition. Inside each block, 48 trials (16 pair of *textures* \times 3 repetitions) were randomly presented to each participant – a total of 144 trials per participant. Participants could practice for an unlimited time at the beginning of each block.

After each block, participants responded to 5-point Likert-scale questions (strongly disagree to strongly agree): i) I identified well, ii) I accomplished the task rapidly; ii) I needed to concentrate to identify well; iv) I felt frustrated; v) I felt confident in my ability to identify the textures and vi) I enjoyed interacting with the device. After terminating all the trials, participants were asked to rank the three *contact* conditions according to their preferences. The average duration of the experiment was 45 mins.

RESULTS

The dependent measures are the *count accuracy*, *id accuracy* and *time*. The *count accuracy* and *id accuracy* are defined as the proportion of correct identifications of respectively the number of different textures and the visual representations of the pair of *textures*. The *time* is defined as the time that a user takes from starting an identification until pressing the “enter” button. The *count accuracy* and *id accuracy* obviously provide a sound measures of whether the users are able or not to perceive a pair of textures. The *time* is more subjective and can only provide an estimation of how difficult might be the identification for participants. We also analyzed subjective responses. All analyses are repeated-measures ANOVA. Tukey tests are used post-hoc when significant effects are found.

Due to a technical issue, the data of two participants were not completely logged. In the following, we report results for the dependent variables and subjective results for 13 participants.

Count Accuracy

In average, we found that participants are relatively able to identify the number of textures perceived for the three *contact*

conditions (see Figure 4). We found significant main effects of *contact* ($F_{2,24} = 28.99, p < .0001$) and *textures* ($F_{15,180} = 9.18, p < .0001$) on *count accuracy*. Without surprise we found that the *count accuracy* was significantly higher for *finger* than *one-handed* by 43.5% ($p < .001$) and *two-handed* by 21.33% ($p < .01$). Post-hoc comparison also revealed that *count accuracy* was significantly lower with *one-handed* than *two-handed* ($p < .05$). Interestingly, there was no significant *contact* \times *textures* interaction ($p = .755$), suggesting that the benefits of *finger* and *two-handed* are consistent across different *textures*.

Immediately after entering the number of textures perceived, participants rated their score of confidence. Friedman tests revealed a significant effect of *contact* on confidence rating ($\chi^2(2) = 135.44, p < .0001$) with participants significantly more confident when using *finger* (respectively *two-handed*) than when using both *chord* conditions (respectively *one-handed*) ($p < .0001$).

Id Accuracy

The overall performance is modest for the three *contact* conditions and especially poor for the *one-handed* condition (see Figure 4). On average, when using fingers from the same hand, our participants were successful at identifying the *textures* associated to the perceived tactile feedback in only 25.81% of all trials. We also found significant main effects of *contact* ($F_{2,24} = 28.51, p < .0001$) and *textures* ($F_{15,180} = 6.43, p < .0001$) on *id accuracy*. Post-hoc comparison revealed that *finger* is significantly more accurate than both *Chord* conditions ($p < .01$) by 110.49% for *one-handed* and 48.68% for *two-handed*. *Two-handed* was also significantly more accurate than *one-handed* ($p < .05$). We also found that the most easily differentiated pairs of textures are the pair of textures composed by the same *densest* textures (P1) (mean=72.64, s.d.=10.69%) followed by the pair of textures composed by the *densest* and the *sparsest* textures (P2) (mean=53.84, s.d.=11.15%). Post-hoc comparison confirms that these pairs are the most perceived ($p < .05$). Interestingly, there was no significant *contact* \times *textures* interaction ($p = .14$), suggesting that: (1) the benefits of *finger* and *two-handed* are consistent across different *textures*; and (2) the benefits of P1 and P2 are consistent across different *contact* conditions.

Immediately after determining the number of textures perceived, participants rated their score of confidence. Friedman tests revealed a significant effect of *contact* on confidence rating ($\chi^2(2) = 130.05, p < .0001$) with participants significantly more confident when using *finger* (respectively, *two-handed*) than when using both *Chord* conditions (respectively *one-handed*) ($p < .0001$).

Time

There were no significant main effects of *contact* ($p=.45$) nor of *textures* ($p = .43$) on *time* with no significant *contact* \times *textures* interaction ($p = .41$), suggesting that the time needed to identify a pair of *textures* is independent on the *contact* used and on *textures* type (mean = 17423, s.d = 2832 ms).

Subjective Results

We recall that participants were asked to rank the *contact* conditions after completing the corresponding trial blocks.

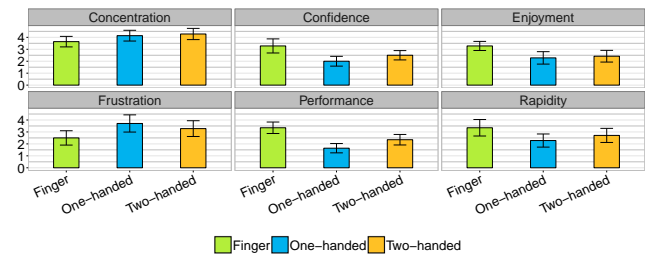


Figure 5: Mean (s.d.) questionnaire responses, with 1=strongly disagree, and 5 = strongly agree.

Overall, *finger* was ranked first 100% of the time, *two-handed* was ranked 77% second and 23% third while *one-handed* was ranked second 23% and third 77%.

Participants were also asked to rate each *contact* condition (see Table 5). Friedman tests revealed a significant effect of *contact* on performance, frustration, confidence and enjoyment. Post-hoc tests using Bonferroni correction showed that one *finger* was significantly better performing and implies more confidence than both *Chord* conditions ($p < .01$) while being less frustrating ($p = .02$) and more enjoyable ($p = .03$) than *one-handed*.

We correlate these findings with participants comments that felt that using one *finger* is easier and demands less mental effort than when using both *chord* conditions. Some quotes are: “Using one finger is easier as I can focus on one texture each time” and “As I don’t success to identify the textures when using two fingers, ..., I prefer to sense the textures using one finger with sequential exploration”. On the other hand, participants felt that it might be more sophisticated to operate in the *two-handed* condition compared to the *finger* condition, but, is much more convenient than the *one-hand* condition. One participant witnessed: “I prefer using two hands to perceive different sensations as it is easier than when I use fingers from the same hand”. All participants felt that the *one-handed* condition is difficult and frustrating. One participant said: “It is really annoying... I am unable to identify the textures” and another said: “I feel very confused, I perceived the feedback in a very fuzzy way”, then added “I feel like if the densest texture is dominant... in fact, the densest texture is more perceived and so the second one seems like if it is the same”, while other participant said “I am unable to differentiate between the textures... I should be very concentrated”.

Methodology for Identifying the Pair of Textures

To better understand how participants were performing, we report here-after the different strategies elaborated by participants in order to identify the *textures* and the number of textures composing it; which is the by-product of the discussions that followed each *contact* block.

Strategies in the Finger condition

Based on participants comments, we state the following:

- **Determining the number of textures.** All participants except two, first try to figure out how many textures they are able to perceive. For this purpose, two main strategies are

used: (1) moving successively the finger on one surface and then on the second one in order to determine if it feels the same or not and (2) exploring many times the first surface and then experience the second surface to determine whether it exposed the same texture or not. If the two surfaces are judged as containing two different textures, then participants explored each surface separately to identify the texture using the next strategies. The two remaining participants proceeded by first identifying the texture on one surface and then the second texture in the second surface to determine whether there are one or two textures.

- **Counting the number of high frictions.** Most of participants counted the number of high frictions and then tried to match the tactile feedback position with its visual.
- **Searching the densest and sparsest textures.** Some participants noticed that, in addition, “*densest and sparsest textures were helpful to classify the texture*” by eliminating the textures that do not contain those types and inversely.

Strategies in the Chord conditions

Two main strategies are used:

- **Concentrating on one finger each time.** Most of participants tried to concentrate on one finger at once in order to identify the corresponding texture.
- **Searching the densest and sparsest textures.** Some participants tried to identify the *densest* or the *sparsest* texture in the corresponding pair, which then helped them identifying the second texture.

Although these two strategies are used in both *chord* conditions, all our participants confirmed that they were relatively unable to identify the whole *textures* in the *one-handed* condition as they felt that “*the densest texture is dominant*”, and hence, does not help them identify the pair of textures. Interestingly, some quotes are: “*using fingers from the same hand requires to be very concentrated as the same part of the brain is used to control the two fingers. However, with two hands, there are two parts of the brain each one can control a different hand, so it is possible to concentrate on one finger at a time*”.

DISCUSSION & DESIGN GUIDELINES

Our key finding is that the users are relatively able to identify the number of different textures composing a pair of *textures* when using two fingers either from the same hand or two hands. However, they are unable to identify different textures especially when using one hand. It is also important to note that using one finger with sequential exploration of the pair of *textures* led to the highest level of performance, increased the confidence and decreased the frustration over synchronous multi-finger exploration. Finally, our analysis suggests that the time needed to identify a pair of *textures* is independent of the *finger* or *chord* in contact with the surface and the *textures*.

Informed by our experimental findings, we outline three relevant guidelines for designing multi-tactile feedback ergonomic and devices design:

- (a) Where possible, privilege one finger sequential exploration of tactile textures over multi-finger synchronous exploration as it is more accurate and increases the confidence.
- (b) The same texture should be provided for fingers from the same hand. Indeed, our participants are not able to perceive correctly more than one texture by hand. Importantly, our participants felt that perceiving more than one texture by hand is very mentally demanding and frustrating.
- (c) Simultaneous different textures should be limited to two textures by user; each one is perceived by a different hand. Our participants prefer *two-handed* over *one-handed* as it is mentally more manageable.

CONCLUSION

In this paper, we conducted the first investigation on users’ perception of simultaneous textures in the context of ultrasonic haptic devices. We showed the potential performance limitations of simultaneously perceiving different tactile textures. We hope that our results will help hardware engineers to design accurate dedicated multi-tactile feedback touch-screens, and will prove useful to researchers and practitioners for improving user’s experience through the design of enhanced multi-tactile feedback techniques and interfaces.

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