Evaluating Vibrotactile Recognition Ability of Geometric Shapes by Using a Smartphone

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Abstract. Attempting to let visually impaired people perceive images instantly taken by a smartphone, Peng (2010) developed a mobile application that outlines images and vibrates the smartphone as user's finger was upon the outlined graphics. The intention is encouraging, but the extent to which people can recognize graphical information via the means is unclear. Hence, this study aimed at evaluating the vibrotactile recognition ability of geometric shapes. Six blindfolded college students participated in this study to discriminate geometric shapes displayed on a smartphone by touching its screen with their forefinger. The phone vibrated as long as the finger touched the graphics. Four shapes, three sizes, and three widths of shape edge were tested as independent variables. Correct rate of judgments and the response time were measured as dependent variables. The results showed that triangle shapes had the highest correct ratio (73.48%), whereas pentagon shapes had the lowest correct ratio (63.59%). Furthermore, the participants required the longest time to judge triangle shapes and the shortest time to judge shapes with width ratio set at 100%. The findings direct new coding methods for display geometric shapes and testing the vibrotactile recognition ability with visually impaired people.

Keywords: Vibrotactile · Recognition · Haptic interface · Graphical information · Smartphone

1 Introduction

To perceive graphical information, visually impaired people normally utilize tools such as thermoform paper, high-density Braille printing, or 3D printing. However, these tools have certain drawbacks of high costs and cumbersome for carrying around. With the rapidly developed technology of mobile devices, there has been researching that is working on mobile applications, attempting to help visually impaired people to perceive images using mobile devices. For instance, the 'Dark Angle' developed by Peng (2010) is a mobile application whose objective was to help visually impaired people to perceive simplified images instantly taken by a smartphone. The intention was encouraging, but the extent to which people can recognize graphical information via the means is unclear. To make practical contributions to similar designs so that to benefit visually impaired people, there is a necessity to study human capabilities and limitations corresponding to the means.

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1.1 Perception of Visually Impaired People

According to United Nations (UN 2013) 285 million people among the world population are visually impaired, of which 39 million are blind and 246 have low vision. Because people who have total blindness have lost their visual ability entirely, they get information through remaining traditional senses: hearing, taste, smell, and touch. Mainly, hearing and touch are used by visually impaired people to perceive textual and graphical information. Hence, many techniques and methods are developed based on these two senses.

To obtain textual information, techniques of Braille and speech synthesizers are developed for visually impaired people. Braille is an embossed language that enables reading textual information through touch. Speech synthesizers are made to provide the spoken output of the information displayed on the computer screen. Recently, new techniques were further developed, such as mobile applications for navigating visually impaired people (Ciaffoni 2014) or even for telling them what are pictured by a smartphone (Image Searcher 2014). These techniques and methods mentioned above have greatly helped visually impaired people effectively perceive textual information. Compared with textual information, however, graphical information is relatively difficult to perceive by visually impaired people based on currently developed devices and techniques.

1.2 Traditional Ways Utilized by Visually Impaired People to Perceive Graphical Information

To perceive graphical information, techniques of collage (Edman 1992), embossed paper (Ina 1996), thermoform paper (Pike et al. 1992), microcapsule paper (McCallum and Ungar 2003), high-density Braille printing (Völkel et al. 2008), and 3D printing (Celani and Milan 2007) are developed for perceiving information such as geographic and orientation maps, mathematical graphs, and diagrams.

However, visually impaired people can only obtain limited graphical information based on the techniques and methods mentioned above. Moreover, they are expensive and cumbersome for personal use. Visually impaired people have difficulties in perceiving graphical information in their surroundings based on these techniques and methods. With the advantages of growing usage of mobile devices, there would be help for visually impaired people to perceive graphical information if relevant methods could be developed.

1.3 Utilization of Mobile Devices to Help Visually Impaired People

Utilizing the camera and vibration functions of new innovative mobile devices, researchers made efforts on developing mobile applications to help visually impaired people recognize environmental images taken by a mobile camera. The "Dark Angle" developed by Peng (2010) is a mobile phone application for helping visually impaired people. The application can simplify the image instantly taken by a smartphone and then process the image into an outlined graphic. It vibrates the smartphone as a moving finger is upon the graphic outlines. Via the vibrotactile feedbacks, the application with a smartphone was expected to help visually impaired people perceive graphical information in their surroundings. This intention of the application was ideal and encouraging. However, human capabilities of perceiving graphical information via the vibration function of the mobile device are unknown.

1.4 Vibrotactile Recognition Abilities of Two-Point Discrimination Threshold, Relative Judgment of Line Thickness, and Absolute Judgment of Line Thickness

To understand the vibrotactile recognition abilities via the vibration function of a smartphone, Lin et al. (2015) evaluated three vibrotactile recognition abilities. In their study, preliminary experiments were designed to assess (1) two-point discrimination threshold, (2) relative judgment of line thickness, and (3) absolute judgment of line thickness. Blindfold college students participated to measure their three vibrotactile recognition abilities. The results showed that (1) the two-point discrimination accuracy rate was great. When the distance between two points was set at 24 mm, the accuracy rate reached 99%; (2) the relative judgment accuracy rate reached the level of 88% when the two-line difference ratio was set at 1.3; (3) the absolute judgment accuracy rate reached the level of 72% when line thickness number was 3.

1.5 Research Objectives

Due to gaps in current findings and the knowledge of using applications such as the Dark Angle, the main objective of this study aimed at evaluating another vibrotactile recognition ability. In the previous study (Lin et al. 2015), the vibrotactile recognition abilities of two-point discrimination threshold, relative judgment of line thickness, and absolute judgment of line thickness were measured. Hence, this study aimed at measuring the vibrotactile recognition ability of geometric shapes. Similar to Lin et al. (2015), this study tested the ability based on the vibration function embedded in general mobile phones.

2 Method

2.1 Participants and Equipment

Three male and three female college students who were different from those participated in the study by Lin et al. (2015), participated in this study to test their vibrotactile recognition ability of geometric shapes. They were informed of the purpose of the study, which was carried out under the ethics of the Human Subject Protection Association in Taiwan.

An HTC Sensation of 4.7″ screen size with a resolution of 480×800 pixels was used in the experiment. The smartphone was fitted with an LCD (liquid-crystal display) capacitive touchscreen that allows the use of fingers to interact with.

A self-developed application, written in Java^{TM} computer programming language using Eclipse Classic 4.2.2, was run on the smartphone. The application displayed geometric shapes on the screen and vibrated the phone as the outlines of graphic were touched.

2.2 Experimental Procedures

The experiment was conducted in a lighted room, in which the participants sat on a chair. After informed consent procedures, the participants were asked to wear a blindfold. As shown in Fig. 1 to perform experimental tasks, the participants held the smartphone with their left hand and sensed the geometric shapes by touching its screen with the forefinger of their right hand. The smartphone vibrated as long as their finger touched the graphics. The participant took their time to discriminate geometric shapes displayed on the screen. Their verbal responses of each experimental trial and the time took to make judgment were recorded.

Fig. 1. Executions of vibrotactile recognition of geometric shapes and the interface of the application.

2.3 Experimental Variables

The independent variables were Shape, Size, and Width Ratio and the dependent variables were the correct rate of judgments and the response time to make the shape judgment. The four Shapes were circle, regular triangle, square and regular pentagon. The three Size values corresponded to the following areas: 3600, 7200 and 14400 pixels

(58.98, 117.96 and 235.93 mm^2). The Width Ratio was defined as the edge width divided by the radius of a circle or the edge-to-center distance of the regular triangle, square and regular pentagon. Three Width Ratio values were 25%, 50%, and 100%. As shown in Fig. 2 a total of 36 graphics were measured (4 Shapes × 3 Sizes × 3 Width Ratios). When testing, the application rotated these graphics through a random angle from 0° to 359° with a scale of one degree. Each experimental combination was repeated four times, giving a total of 144 graphics for the experiment.

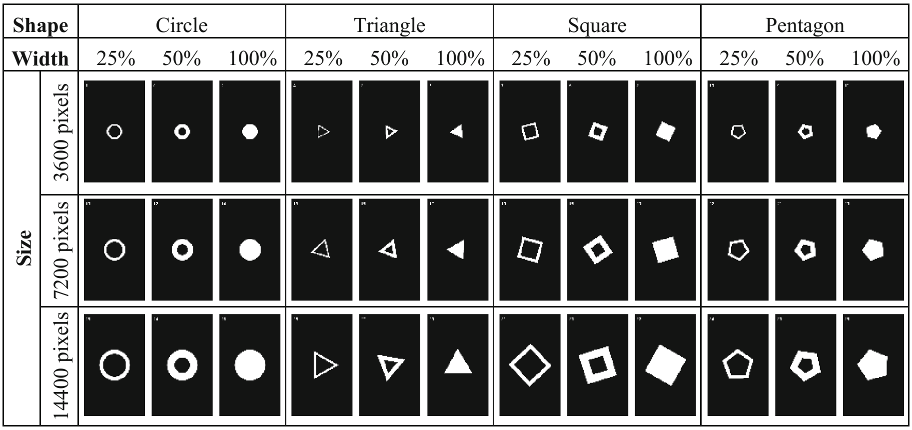

Fig. 2. Geometric graphics tested in the experiment.

3 Results

3.1 Proportion of Correct Judgments

Analysis of variance was performed on the proportion of correct judgment using a mixed model with Shape, Size, and Width as fixed effects and Participant as random, in which the interaction effects among these three fixed effects were analyzed. The effect of Participant was considered as a blocking effect, which was not interested in. The results showed significant effects of Shape ($F_{3,823} = 15.02$, $p < 0.001$) on the proportion of correct judgments. As shown in Fig. 3 the proportion of correct judgments, from high to low, was triangle, square, circle, and pentagon. The triangle (54%) was significantly greater from circle and pentagon in performance and the pentagon (25%) was significantly lesser from triangle and square in performance. There was no significant main effect of Size on the proportion of correct judgment.

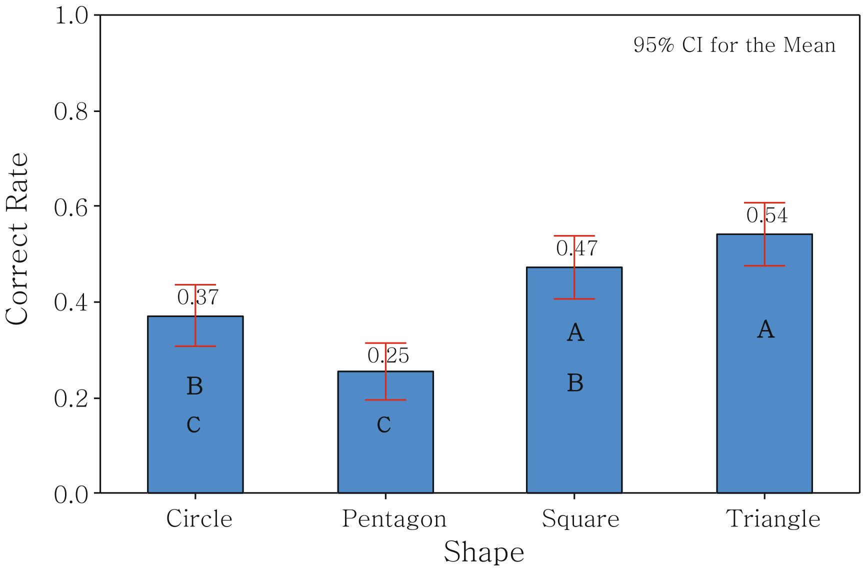

Fig. 3. The effect of shape on correct rate. Means that do not share a letter are significantly different.

3.2 Response Time

Analysis of variance was performed on the response time using a mixed model with Shape, Size, and Width as fixed effects and Participant as random, in which the interaction effects among these three fixed effects were analyzed. Again, the effect of Participant was considered as a blocking effect, which was not interested in. The results showed significant effects of Shape ($F_{3,823} = 2.77$, $p < 0.05$) and Width ($F_{2,823} = 3.62$, $p < 0.05$) on the proportion of correct judgments. As shown in Fig. 4 although a Tukey comparison showed no significant difference among shapes in response time, the participants spent relatively greater time (73.48 s) when judging shapes of triangle. As shown in Fig. 5 the participants spent significant lesser response time (63.59 s) while judging shapes with the width ratio at 100%. There was no significant main effect of Size on the response time, neither.

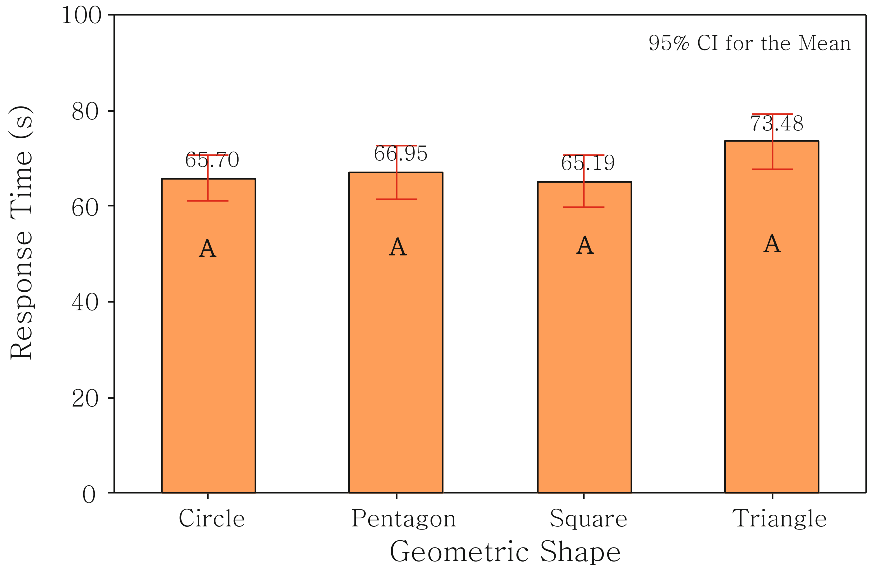

Fig. 4. The effect of shape on response time. Means that do not share a letter are significantly different.

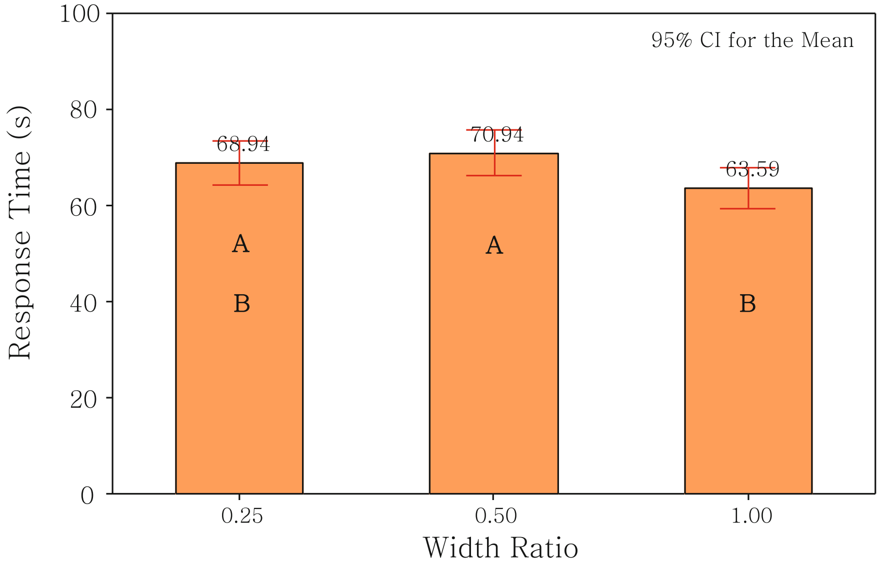

Fig. 5. The effect of width ratio on response time. Means that do not share a letter are significantly different.

4 Discussion

This preliminary study tested human vibrotactile capability in using the vibration mode of a smartphone to recognize geometric shapes. The participants were blindfolded so they were not using the visual sense, but restricted to sensing of vibration via the fingertip. The purpose was to test the vibrotactile recognition ability so that we could interpret how well visually impaired people can perceive graphical information via the vibration function of a touchscreen smartphone. It was anticipated that there were performance differences between sighted users and visually impaired people, so the results measured with the sighted college students was used to give an approximate prediction of how visually impaired people would perform the recognition.

Compared to the three vibrotactile recognition abilities measured by Lin et al. (2015), the participants had relatively poor performance in judging geometric shapes. In the case, circle, regular triangle, square and regular pentagon were tested. The participants had the greatest correct ratio of judgment when discriminating triangle shapes, but this only researched a level of 54%. Regarding response time, the participants had the shortest time when judging shapes with a width ratio set at 100%, but in average 63.59 s was required to make a judgment. These results indicate that the participants had a great confusion of judgment.

Based on the findings of this study and the previous study (Lin et al. 2015), how would the application of Dark Angle be helpful for visually impaired people? Frankly, we doubt visually impaired people can utilize it to perceive graphical information that is complicated. However, we do believe that the vibration function of a smartphone may deliver graphical information to a certain limited extent. We observed the participants discriminated geometric shapes using the strategy that recognizing the appearance of shape corners. This phenomenon directs future studies with simplified shapes and applying coding systems with visually impaired people. With better coding systems are applied, we expect the vibrotactile modality may be used for certain purposes.

5 Conclusions

This study tested a vibrotactile ability of geometric shapes when the monotonic vibration function embedded in a smartphone was used to provide vibration feedback to the blindfolded participants. The results reveal the limitations of perceiving graphical information via the means. At the best, the participants had the greatest correct ratio (54%) of judgment when discriminating triangle shapes and had the shortest time (63.59 s) when judging shapes with a width ratio set at 100%. To implement similar vibrotactile modalities and make mobile devices assistive to visually impaired people, more investigations of human capabilities and limitations corresponding to this means is critical. Future research should involve an adequate number of blind participants and test new coding systems.

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