Judging Hardness of an Object from the Sounds of Tapping Created by a White Cane

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***Abstract*—The white cane plays a vital role in the independent mobility support of the visually impaired. Allowing the recognition of target attributes through the contact of a white cane is an important function. We have conducted research to obtain fundamental knowledge concerning the exploration methods used to perceive the hardness of an object through contact with a white cane. This research has allowed us to examine methods that enhance accuracy in the perception of objects as well as the materials and structures of a white cane. Previous research suggest considering the roles of both auditory and tactile information from the white cane in determining objects' hardness is necessary. This experimental study examined the ability of people to perceive the hardness of an object solely through the tapping sounds of a white cane (i.e., auditory information) using a method of magnitude estimation. Two types of sounds were used to estimate hardness: 1) the playback of recorded tapping sounds and 2) the sounds produced on-site by tapping. Three types of handgrips were used to create different sounds of tapping on an object with a cane. The participants of this experiment were five sighted university students wearing eye masks and two totally blind students who walk independently with a white cane. The results showed that both sighted university students and totally blind participants were able to accurately judge the hardness of an object solely by using auditory information from a white cane. For the blind participants, different handgrips significantly influenced the accuracy of their estimation of an object's hardness.**

I. Introduction

Although white canes play a vital role in supporting the independent mobility of visually impaired people, the following issues have been raised: the perceptible areas are limited; unless a white cane detects an object, the user cannot recognize it as an obstacle, and users may grow fatigued from continuously swinging a cane from side to side in order to obtain information about obstacles in the direction of the forward movement. Therefore, advancement for the aforementioned issues has been considered, including the improvement of materials used to build canes and the development of canes, such as the electronic white cane, to solve these problems. Understanding the kind of information obtained using the currently used white cane is necessary in order to develop a white cane in line with users' demands. Furthermore, clarifying this point will contribute to the development of a design that supporting the mobility of the visually impaired. We have conducted research in order to obtain fundamental knowledge concerning the exploration methods used to perceive the hardness of an object through contact with a white cane. This research has allowed us to examine methods that enhance the accuracy in perceiving objects as well as the materials and structures of a white cane. In previous research, results suggested that both auditory and tactile information conveyed through tapping on an object should be considered because they aid a white cane users' ability to perceive the hardness of an object. Moreover, in training courses for the visually impaired, the following three methods are taught for holding a white cane (Fig. 1): 1) standard grip—stretch the index finger across the flat face of the grip and lightly hold the grip with the thumb and other three fingers, 2) pencil grip—hold the grip like a pen or pencil, and 3) traditional grip—press the thumb on the flat face of the grip and hold the grip with the four fingers. Different methods can be selected depending on the circumstances. Using different methods may alter the use of different body parts that receive sensory information about an object and impact the reception of different input information from a hand. Thus, the relationship between the hardness of rubber samples and their perceived hardness were investigated using the three types of holding methods in order to examine the influence of these holding methods on the perceived hardness. The results indicate that the holding methods for a white cane influence the perceived hardness of an object and that a pencil grip is the most sensitive method of the three.

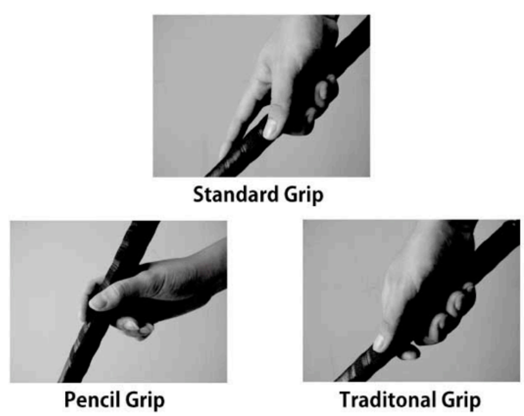

Figure 1. The three methods taught for holding a white cane.

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The goals of this study are 1) to determine whether people can perceive the hardness of an object using the tapping sounds of a white cane (i.e., auditory information) and 2) to examine whether based on sound, different white cane holding methods influence performance. To achieve the goals of this paper, we used the method of magnitude estimation for measurement and three methods of holding a white cane as a variable.

II. Experiment 1

A. Purpose

The purpose of Experiment 1 is to identify the relationship between sounds made by tapping a rubber panel with a white cane and the perceived hardness of the rubber using magnitude estimation in sighted university students.

B. Method

1) Stimulation and equipment

Square rubber panels measuring 12 mm thick with a face of 300 × 300 mm (Showa Rubber Co., Ltd.) were used for estimating the hardness. There were eight degrees of hardness ranging from JIS-A 20° to 90° in ten-degree increments (measured with Teclock GS-719G Type A durometer). The white cane (G&OM-Aids, Inc.) used in the experiment had a 1200 mm aluminum alloy shaft (light metal) with a rubber grip of 260 mm and a nylon tip of 75 mm (Fig. 3). The cane measured 200 g in weight.

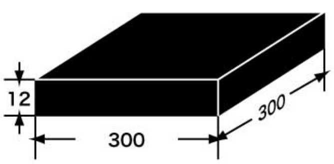

Figure 2. Size of rubber panels.

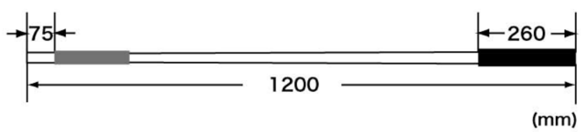

Figure 3. Size of white cane.

There are two types of sound conditions: 1) playback of recorded tapping sounds and 2) sounds produced on-site by tapping. Two types of original sounds were used for playback conditions: 1) automated method—a device was used to create sounds for recording, placed at a height of 90 cm to tap a rubber panel with a white cane, under the assumption this to be the standard height at which adults hold a cane to tap on the object (Fig. 4) and 2) manual method—an experimenter created recorded sounds by manually tapping a rubber panel with a white cane (Fig. 5). Each of the three methods—standard, pencil, and traditional grips—of holding a white cane was used for manual tapping. Both types of playback sounds were recorded in an anechoic chamber. A shotgun microphone (Line + Gradient Condenser Microphone AT815: Audio-Technica Corporation) and an audio unit (FireWire AUDIO CAPTURE FA66: Roland) were used to capture the sounds. A PC (MacBook Pro mid 2010: Apple Inc.) and an application (Audacity 1.3.12: Dominic Mazzoni) were used to record the sounds. For sound playback, a loudspeaker (TD510MK2: FUJITSU TEN LIMITED) was used, whose features are as follows: speaker unit 10 cm in length, cone shape, full range, composed of fiberglass, playback frequency range of 42 Hz to 22k Hz (−10 dB), efficiency of 84 dB/W·m, permissible input of 25 W/50 W (rated/maximum), impedance of 6 Ω, external dimensions of 255 × 391 × 381 mm, and approximately 9.5 kg in mass. A PC (MacBook Air mid2012: Apple Inc.) was used for playback.

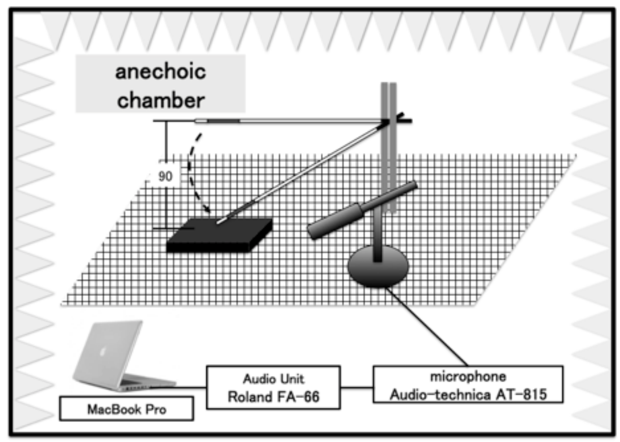

Figure 4. Automated method for recording a sound.

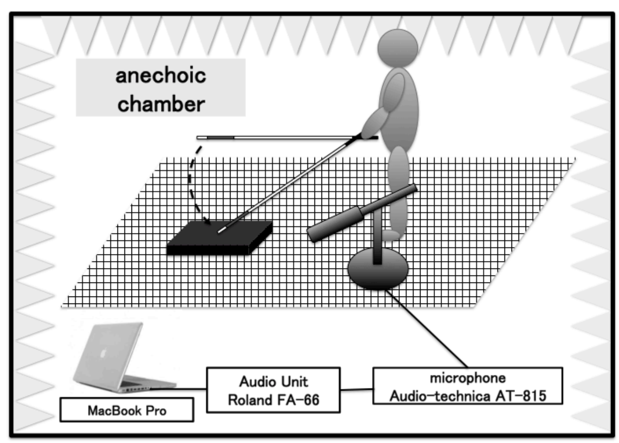

Figure 5. Manual method for recording a sound.

2) Participants

Participants were five sighted university students who had never used a white cane. They wore eye masks during the experiment. To ensure that participants had no hearing problems, hearing examinations were conducted for each participant. To ensure that there were no problems with tactile sensation, tactile two-point discrimination was tested on the index finger pulp of the dominant hand. Participants also practiced magnitude estimation using a wooden disk (diameter as a variable).

3) Procedure

The first task was performed using the playback condition. For this task, the participants stood on a seat 40 cm in height and listened to a recorded sound from the loudspeaker, which was placed in front of the seat. The distance between the center of the seat and the speaker unit was 109 cm. In addition, a bar, 139 cm in height, was placed beside the seat for the participants to hold to ensure their physical stability (Fig. 6). The experimenter played back recorded sounds from a loudspeaker in a random order. The participant made a magnitude estimate of the sounds' hardness. A standard stimulus or modulus was not used, and the participants were instructed to state a number that they felt corresponded to the hardness of each rubber panel.

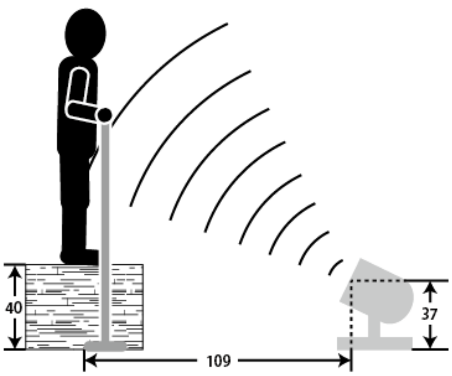

Figure 6. Experimental scene: a participant listening to sounds from a loudspeaker. (unit: cm).

The second task was performed using on-site sounds of tapping on a rubber panel with a white cane. For this sound condition, an experimenter used a standard grip to hold the white cane and tapped the rubber panel. Participants were asked to stand on the floor, and a rubber panel was placed in front of them. The distance between the centers of the participant's body and the rubber panel was 109 cm. When the experimenter used a white cane to tap different rubber panels in a random order, the participant made magnitude estimates of the objects' hardness based on the sounds.

Magnitude estimation was conducted once for each condition.

C. Results

Geometric means were calculated for the magnitude estimates, plotted on a double logarithmic graph with rubber and perceived hardness on the horizontal and vertical axis, and approximated with a power function. We used an application (Microsoft Excel for Mac2011 ver. 14.39) for this processing. The size of the exponent has a major effect on the nature of the relationship between the intensity of the stimulus and the magnitude of the psychological reaction. The magnitude of the psychological reaction increased in proportion to the stimulus's physical intensity raised to some exponent. If the exponent is exactly one, a relationship between the intensity of the stimulus and the magnitude of the psychological reaction has one-to-one correspondence. When the exponent is greater than one, a small increase in the intensity of the stimulus is accompanied by a huge increase in the magnitude of the psychological reaction. If the exponent is less than one, a large increase in the intensity of the stimulus is accompanied by only a small increase in the magnitude of the psychological reaction. When the exponent is less than 1, when the hardness of a rubber plate is small (soft), sensitivity is good; however, as the hardness became higher, sensitivity becomes lower. When the exponent is larger than 1, when hardness of a rubber plate is larger (hard), sensitivity for the changes in the hardness is high; however, when hardness is smaller (softer), sensitivity is low. In the graph that power functions placed in logarithmic coordinates, they are plotted straight lines. The slope of the line corresponds to the exponent of the power function governing the growth of the sensation. When the exponent is 1, the line plots one-to-one correspondence between the hardness of the rubber panel and the estimate value. When the exponent is less than 1, the lines rise gradually. When the exponent is larger than 1, the lines rise sharply.

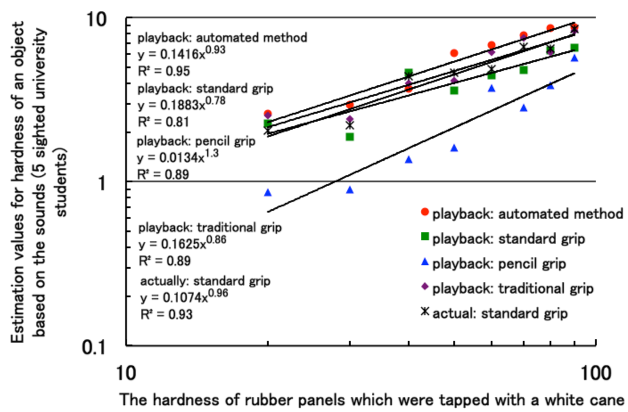

Figure 7. The relationship between the hardness of rubber panels perceived by 5 sighted students using the tapping sounds and actual hardness of the rubber panels.

The results of the university student participants are as follows (Fig. 7). The exponent for the automated playback condition was 0.93. Because the exponent was close to 1, the perceived hardness increased with the rubber panel's actual hardness. This implies that sensitivity is high for the changes in hardness. The exponent for the standard grip playback condition was 0.78. An exponent lower than 1 suggested that when the rubber panels' degree of hardness was low (soft), participants were sensitive to change; as the hardness increased, sensitivity decreased. Concisely, sensitivity for the changes in the hardness is somewhat lower than that to the automated playback condition. The exponent for the pencil grip playback condition was 1.30. An exponent larger than 1 suggested that when the degree of hardness of the rubber panels was high (hard), participants were sensitive to changes in hardness; however, when the hardness decreased, the sensitivity also decreased. The exponent for the traditional grip playback condition was 0.86, similar to the standard grip playback condition, suggesting that participants were most sensitive when the degree of hardness was low. The exponent for the standard grip on-site condition was 0.96. As with the automated playback condition, the exponent was close to 1, suggesting that participants were sensitive to changes in hardness across the entire range.

III. Experiment 2

A. Purpose

The purpose of Experiment 2 is to identify the relationship between the sounds made by tapping a rubber panel with a white cane and the perceived hardness of the rubber using magnitude estimation in visually impaired university students.

B. Method

1) Stimulation and equipment

Stimulation and equipment were the same as in Experiment 1.

2) Participants

The participants were two totally blind university students (Table 1) who regularly used white canes to walk independently. The other conditions were the same as those of the participants of Experiment 1.

TABLE I. ATTRIBUTES OF BLIND PARTICIPANTS

ID	*age*	*age of becoming blind*	*years spent using white cane*
A	21	around 7	16
B	23:7	8:11	13:10

(years: months)

3) Procedure

Procedure was the same as in Experiment 1.

C. Results

The results of the visually impaired participants are as follows (Fig. 8).

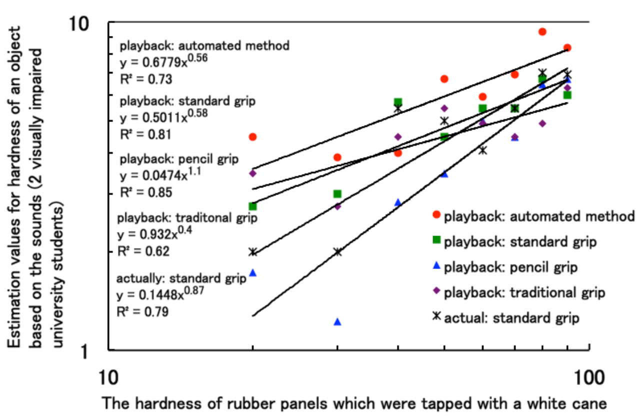

Figure 8. The relationship between hardness of rubber panels perceived by 2 totally blind students using tapping sounds and hardness of the rubber panels.

The exponents for the automated method playback, the standard grip playback, the traditional grip playback, and the standard grip on-site conditions were 0.56, 0.58, 0.40, and 0.87, respectively. Under these conditions, all exponents were less than 1. This indicates that when the degree of hardness of a rubber panel was low (soft), the participants were sensitive to changes in hardness. However, as hardness increased, the sensitivity decreased. In short, we can say that the sensitivity is low for the changes in the hardness. The exponent for the pencil grip playback condition was 1.10. An exponent close to 1 indicated that the perceived hardness increased as the rubber panels became harder. Concisely, sensitivity for the changes in the hardness can be considered to be high. In this study, the two totally blind participants were able to perceive the hardness of an object by the sound under the pencil grip playback and the standard grip on-site conditions.

IV. Discussion

Different perceptions of material hardness were observed between sighted students and totally blind participants. However, based on these results, estimating the hardness of a target using tapping sounds created with a white cane is possible. Furthermore, different methods of holding a cane significantly influence the accuracy of the totally blind participants' estimation of the hardness of an object. But more white cane users should be required to participate in an experiment to confirm if the results of this study can be applied to the whole totally blind population.

The results indicate that further investigations on the following points would be effective in order to support white cane users' mobility: 1) studying the relationship between the frequency and a sense of hardness using a white cane, 2) devising materials and structures of a white cane by stressing the sound frequency components related to the hardness of an object when tapping and 3) developing landmark designs using materials with features that differentiate the sounds and hardness of surrounding materials. Moreover, more features of an object (e.g., texture), other than hardness, should be investigated further.

Acknowledgment

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References

[1] K. Nunokawa, S. Ino, and T. Ifukube, "The Fundamental Research on Tactile Perception of A Object through The Cane," in 2008 Proc. Human Interface Symposium, pp. 527–530.

[2] Nunokawa, Kiyohiko & Ino, Shuichi, "An Experimental Study on Target Recognition Using White Canes" in Proc. the 32nd Annual International Conference of the IEEE Engineering in Medicine and Biology Society "Merging Medical Humanism and Technology," 2010, pp.6583-6586.

[3] K. Doi, A. Sugama, T. Nishimura, S. Ino, K. Nunokawa, M. Sugiyama, K. Kosuge, and A. Miyazaki, "Influence of the Weight of White Canes on Muscle Load of the Upper Limbs," World Congress on Medical Physics and Biomedical Engineering, IFMBE Proceedings, 2011, pp.2019–2022.

[4] K. Nunokawa, S. Ino, and T. Ifukube, "A psychophysical study of tactile perception on an object hardness according to the difference of how to grasp the white cane," in 2011 Proc. Human Interface Symposium, pp. 853-854.