Vibrotactile Amplitude Discrimination on the Wrist of Visually Impaired People

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Abstract

Support for spatial orientation and mobility of the blind and partially sighted people is still a hot and unsolved topic. It is well known that in supporting devices non-acoustic communication is recommended due to the role of the sense of hearing in the spatial orientation of the visually impaired people. Knowledge about discriminative ability of touch is crucial when designing devices which use tactile interfaces. The paper presents results of psychophysical studies connected with vibration perception on the wrist of blind and partially sighted people. The presented research examined the ability to identify the changes of amplitude of vibration on the wrist. Research was carried out on students of Special Schools for the Blind and Partially Sighted Children in Krakow. Thirty blind, partially and normal sighted people were examined. Transformed up/down method was used to determine vibrotactile amplitude discrimination threshold. Thresholds were obtained on the ventral wrist at 5 frequencies: 25, 32, 63, 125 and 250 Hz. Results were examined to find factors which could influence the threshold value.

Keywords: vibration perception, vibrotactile amplitude discrimination, blind people

1. Introduction

Visual stimuli constitute approximately 80% of all the information reaching the human brain [1]. People that could not perceive visual stimuli use the active cooperation of all the other senses to compensate the lack of sight. This mechanism is called the compensation. Blind people use other senses: sense of touch, sense of hearing, sense of smell and additional skills called algorithms and obstacle sense. Obstacle sense is describe as feeling a tingling, or „shadow” of the obstacle when that person is near the obstacle. Since there are no additional receptors on the body of blind people it is considered a synthesis of sharpened hearing and touch (like hearing the reflected sound and feeling the changes in the air flow on skin). Despite the popular opinion, the most important sense of a blind person when moving is not touch but hearing. Because hearing is the long-range sense. Therefore, devices supporting spatial orientation should use vibration interfaces. These devices should not occupy user's hands because of the role of touch in movement, but also for practical reasons [2]. Therefore, the researchers decided to create a vibrating bracelet supporting spatial orientation.

The hereby paper presents the part of the psychophysical research carried out to specify vibration perception on the wrist. The starting point of the described tests were the results of the measurements of absolute vibration thresholds on the proximal phalange and ventral wrist [3, 4]. The presented research examined the ability to identify the changes of the vibration amplitude on the wrist for selected frequency. The measurements were carried out using the adaptive method 1 up/2 down on a measuring stand specially designed for the needs of the described test.

2. Methodology

The research method including the measuring stand description, psychophysical methods used in experiment measurement procedure is described in detail below.

2.1. *Measuring stand*

The schematic diagram of the measuring stand for testing the differential vibration thresholds on the wrist using the adaptive method 1 up/2 down is shown in Figure 1. The measuring procedure was implemented and controlled by computer with LabVIEW software. Vibration stimuli were sent through 4-channel voltage output module NI 9263 (National Instrument) to Apart MB-150 amplifier and generated by the mini modal shaker TMS 2004E (The Modal Shop). The measurement conditions were controlled by the accelerometer PCB M354C03 and pressure sensor and connected with the computer through the 4-channel input module NI 9234. The masking signal (pink noise) was sent through the computer sound card to the Beyerdynamic DT 770 pro headphones.

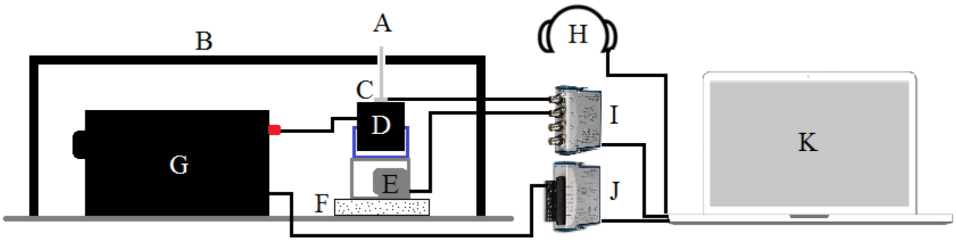

Figure 1. Schematic diagram of the measuring stand for testing the differential vibration thresholds on the wrist [5].
A – probe, B – support of the subject's forearm,
C – accelerometer PCB M354C03, D – modal shaker TMS 2004E,
E – pressure sensor, F – vibration insulation,
G – amplifier Apart MB-150,
H – closed headphones Beyerdynamic DT 770 pro,
I – 4-channel input module NI 9234,
J – 4-channel voltage output module NI 9263,
K – computer with LabVIEW software

2.2. *Psychophysical adaptive procedures*

Discrimination of changes in the vibration amplitude is the ability of the sense of feeling to perceive changes in vibration amplitude over time. In other words, this ability allows a person to notice the difference in amplitude of two vibration signals [6].

Adaptive up/down method was chosen to study the vibrotactile amplitude discrimination threshold on the wrist [7, 8]. The method was selected based on pilot studies carried out using the method of constant stimuli. Five frequencies were selected for the study: 25; 31.5; 63; 125; 250 Hz. The frequencies were selected based on results and analyzes of absolute vibration thresholds on the ventral wrist described by Wiciak et al. [4]. Vibrations of selected frequencies stimulate FAI mechanoreceptors (25; 31.5 and 63 Hz) and FAII mechanoreceptors (125 and 250 Hz).

The algorithm of up/down method with two interval forced-choice (2IFC) was implemented in the LabVIEW environment [9]. The difference between the standard (reference) and variable (compared) stimulus in each first attempt was such that the subjects clearly felt it and provided the correct answer. In this phase of the algorithm, after each correct answer there was a reduction of the difference between the standard and variable stimulus by a double step value. After the first incorrect answer (first reversal), the main phase of procedure 1 up/2 down followed (Figure 2).

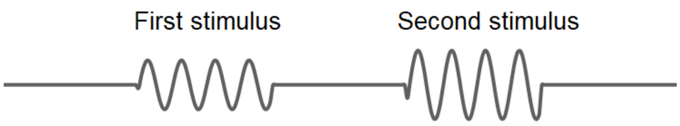

Figure 2. Vibration amplitude discrimination – stimulus sequences given by the modal shaker to the wrist

In the next attempt, the difference between the stimuli was greater by the value of the step. From now on, the reduction of the difference between stimuli in the trial could only take place after two successive correct answers and was the value of the step. However, after each wrong answer, or a sequence of correct and wrong answer, the difference between the stimuli in the sample was increased by the step value. The end of the study occurred after 8 retreats. The test conditions are summarized in Table 1.

Table 1. Vibrotactile amplitude discrimination threshold – test conditions

		Vibrotactile amplitude discrimination threshold
Stimulus	**Standard stimulus**	Sinusoidal signal with frequencies 25; 31.5; 63; 125; 250 Hz and intensities equal to the vibrotactile perception threshold for a given frequency
	Variable stimulus	Stimuli level varying in the range of 100 – 150 dB ref. 10^{-6} m/s^2
	Probe	Flat cylinder with a diameter of 5 mm, without surroundings, with controlled skin contact force in the range of 0.1 – 0.2 N
Method		Adaptive method 1 up/2 down
Task		Two interval forced-choice (2IFC)
Analysis		Vibrotactile amplitude discrimination threshold for each tested frequency was calculated as the arithmetic mean of the stimulus reversal values without the first
Measure		dB ref. 10^{-6} m/s^2

3. Results analysis and discussion

The research group consisted of 30 people: 10 blind people, 10 partially sighted people and 10 normally sighted people. There were 5 women and 5 men aged 18 to 28 years in each group. Median value of the amplitude discrimination threshold received for 30 people is shown in Figure 3.

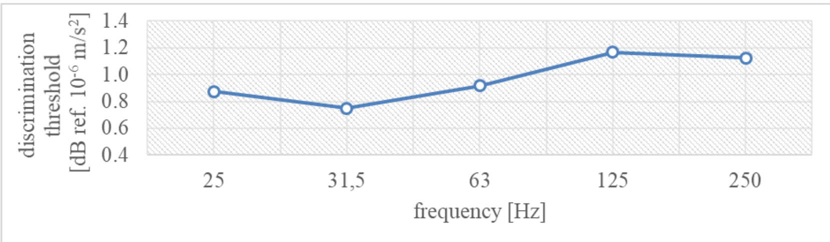

Figure 3. Median value of vibrotactile amplitude discrimination thresholds measured on the wrist

The main purpose of the results analysis was to check if the values of vibrotactile amplitude discrimination thresholds for blind people differ from those for people with normal sight. Additional analysis was conducted to check whether the frequency and the gender of the subject affects the value of the vibrotactile amplitude discrimination threshold. Nonparametric tests were used for the analysis because the obtained threshold values do not follow the normal distribution. The influence of individual factors such as the degree of visual disability of the subjects as well as stimulus frequency (more than two groups) were tested using the Kruskal-Wallis test (1) and gender (two groups) were tested using the Kolmogorov-Smirnov test (2) [10].

$$H = \frac{12}{N(N+1)} \sum_{i=1}^{p} \frac{R_i^2}{n_i} - 3(N+1), \tag{1}$$

where: H – Kruskal-Wallis test; N – number of all observations; p – number of compared groups; R_i – the sum of ranks in a given group; n_i – number of observations in a given group.

$$D_n = \max_x \left[F_n(x) - F(x) \right], \tag{2}$$

where: F_n – empirical distribution function.

The results were also analyzed in terms of creating design guidelines for devices supporting spatial orientation of the blind and partially sighted people with vibration interfaces.

Figure 3 shows the median value of vibrotactile amplitude discrimination thresholds depending on the frequency. There were differences in the threshold values in the range of 0.4 dB. To check if there are statistically significant differences between the results for the five frequencies the Kruskal-Wallis test was performed. The analyzed results follow the assumptions required to perform the Kruskal-Wallis test. The null hypothesis (H_0) and the alternative hypothesis (H_a) were stated as follows:

H_0 – values of vibrotactile amplitude discrimination thresholds do not depend on the frequency;

H_a – values of vibrotactile amplitude discrimination thresholds depend on the frequency in at least two of the observed groups.

Value H = 12.96364 (p = 0.0115 is less than 0.05) is in the critical area of statistics. As a result, the null hypothesis can be rejected, and it can be assumed that there is a statistical difference between vibrotactile amplitude discrimination thresholds for different frequencies, for at least two measured frequencies. Further analyzes (Table 2) showed statistically significant lower thresholds for 31.5 Hz versus 125 Hz. No statistically significant differences were found between the other frequency pairs [5].

Table 2. P-value for multiple (two-sided) comparisons
Kruskal-Wallis Test: H = 12.96364 p = 0.0115

	25 Hz	**31.5 Hz**	**63 Hz**	**125 Hz**	**250 Hz**
25 Hz		1.000000	1.000000	0.228343	1.000000
31.5 Hz	1.000000		1.000000	**0.006752***	0.234639
63 Hz	1.000000	1.000000		0.577850	1.000000
125 Hz	0.228343	**0.006752***	0.577850		1.000000
250 Hz	1.000000	0.234639	1.000000	1.000000	

Figure 4 compares the median values of vibrotactile amplitude discrimination thresholds for men and women. It was noticed that men achieved lower or the same as women thresholds for low frequencies (received by FAI mechanoreceptors). The opposite situation occurs at high frequencies (received by FAII mechanoreceptors).

The Kolmogorov-Smirnov test was performed to check whether the observed differences of thresholds in individual groups were statistically significant.

The null hypothesis (H_0) and the alternative hypothesis (H_a) were stated as follows:

H_0 – values of vibrotactile amplitude discrimination thresholds do not differ between women and men;

H_a – values of vibrotactile amplitude discrimination thresholds differ between women and men.

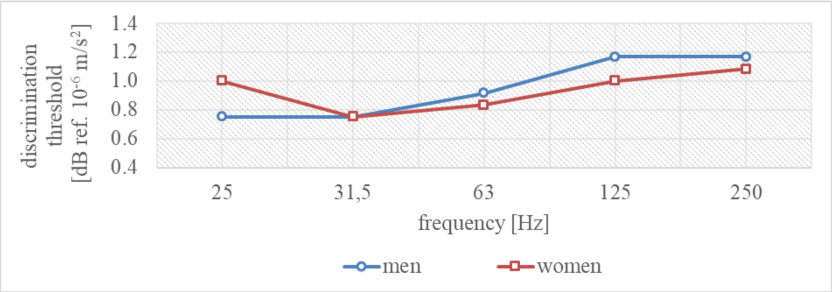

Figure 4. Median value of vibrotactile amplitude discrimination thresholds measured on the wrist depending on the gender of the subjects

According to the Kolmogorov-Smirnov test the p value for comparison between different frequencies is greater than 0.1 ($\alpha = 0.05$). Therefore, the null hypothesis could not be rejected. For all tested frequencies, it was found that the observed differences in the results of men and women are not statistically significant. Further analyzes were conducted for all subjects without considering the division by gender.

Figure 5 compares the median values of vibrotactile amplitude discrimination thresholds for the blind, partially sighted and normally sighted people.

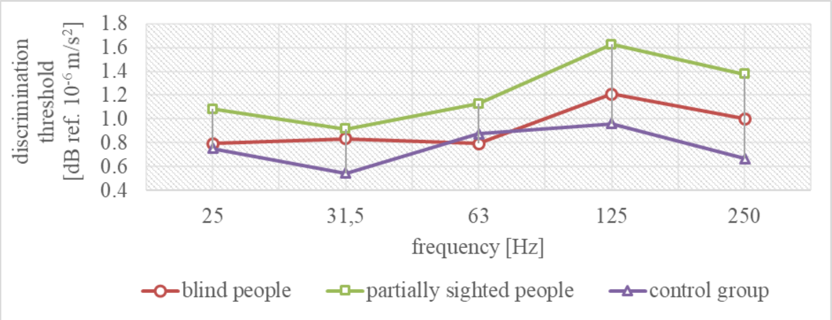

Figure 5. Median value of vibrotactile amplitude discrimination thresholds measured on wrist depending on the degree of visual disability of the subjects

To check if there were statistically significant differences between the results for the blind, partially sighted and normally sighted people the Kruskal-Wallis test was performed. The null hypothesis (H_0) and the alternative hypothesis (H_a) were stated as follows:

H_0 – values of vibrotactile amplitude discrimination thresholds do not depend on the degree of visual disability of the subjects;

H_a – values of vibrotactile amplitude discrimination thresholds depend on the degree of visual disability of the subjects in at least two of the observed groups.

For all tested frequencies the value of H is outside the critical range (Table 3). As a result, null hypothesis cannot be rejected, and it can be assumed that values of vibrotactile amplitude discrimination thresholds do not depend on the degree of visual disability of the subjects for following frequencies: 25; 31.5; 63; 125 and 250 Hz.

Table 3. The Kruskal–Wallis test by ranks

Frequency	**Kruskal-Wallis Test – grouping variable – degree of visual disability**
25 Hz	H = 2.724989 p = 0.2560
31.5 Hz	H = 5.339776 p = 0.0693
63 Hz	H = 3.410659 p = 0.1817
125 Hz	H = 1.323420 p = 0.5160
250 Hz	H = 8.145166 p = 0.0170

3. Conclusions

The paper presents the results of the research on vibration perception of blind, partially sighted and normally sighted people. Based on the research presented in the paper vibrotactile amplitude discrimination thresholds for frequencies 25; 31.5; 63; 125 and 250 Hz were determined. Additional analysis was conducted to check whether the frequency and the gender of the subject affect the value of vibrotactile amplitude discrimination threshold. Based on the analyzes and statistical tests it was found that:

- just-noticeable difference of vibration amplitude on the wrist is equal around 1 dB;
- there are no statistically significant differences between the most tested frequency pairs. Vibrotactile amplitude discrimination threshold is statistically significant lower for 31.5 Hz versus 125 Hz;
- there are no statistically significant differences between values of vibrotactile amplitude discrimination thresholds for men and women;
- there are no statistically significant differences between values of vibrotactile amplitude discrimination thresholds for blind, partially sighted and normally sighted people.

In addition, the analysis allowed the development of design guidelines for vibration interfaces considering the human factor, with emphasis on the needs of visually impaired people. When designing vibration interfaces worn on the wrist using 25 frequencies; 31.5; 63; 125 and 250 Hz or similar, observe the following:

– it is recommended to use signals with different levels of amplitude, because changes in this vibration signal parameter are well recognized by the human sensory system;
– it is recommended to use amplitude differences greater than 1 dB for signals with frequencies up to 63 Hz and amplitude differences greater than 2 dB for signals with frequencies above 63 Hz.

Acknowledgments

The project described in this paper has been executed within the project No. 16.16.130.942 in Department of Mechanics and Vibroacoustics of AGH University of Science and Technology in Cracow, Poland.

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