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SUBJECTIVE LOUDNESS COMPARISON BETWEEN A HEAD PHONE AND A BONE VIBRATOR

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A headphone will cover a listener's outer ear and reduce his / her auditory situation awareness of the surrounding. Unlike headphone, bone vibrator can transmit sound without covering the outer ear. In order to study the benefits of replacing headphone with bone vibrator, factors affecting the subjective loudness comparison between a headphone and a bone vibrator will need to be investigated. Three experiments have been conducted to study the effects of practice, static contact force, and the order of presentation on loudness comparison ratings between a 1 kHz tone transmitted via a headphone and a bone vibrator. Results showed that neither practice nor order of presentation affect the loudness comparison data significantly. As the static contact force between a bone vibrator and a mastoid increased from 0.1 to 3.6N, the perceived loudness peaked at 0.7N and then decreased.

Introduction

The most common way to transmit a personal message is through the use of a head phone. However, a head phone will cover the outer ear and reduce the ability to localize surrounding sound sources. This can reduce the auditory situation awareness of one's surroundings. Unlike a head phone, a bone vibrator, readily available in the market as a hearing aid, can transmit sound messages to a person without covering the outer ear. It is hypothesized that a person listening to a bone vibrator has a better auditory situation awareness than a person listening to a head phone. In order to test this hypothesis, it is necessary to compare his / her ability to localize secondary sound sources while listening to a primary sound message transmitted through a bone vibrator and a head phone. However, before such a comparison can be made, the primary sounds transmitted via the bone vibrator and headphone have to be set to the same loudness. The most direct method to calibrate the loudness difference between a bone vibrator and a head phone is by subjective assessment. As there are many factors which may affect the sound transmission through a bone vibrator, studies have been conducted to study the effects of these factors.

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The aims of these studies are to investigate the effects of practice, presentation order, and static contact force on the subjective comparison of loudness between signals presented via a headphone and a bone vibrator. Three experiments have been conducted and it was hypothesized that: (i) repeated practices would increase the consistency of loudness assessment of sound signals; (ii) the order of presenting a pair of sound signals will affect the loudness assessment between them; and (iii) increasing static contact force between a bone vibrator and the mastoid would first increase the loudness and then reduce it.

Details of experiments

Task and apparatus

In each of the three experiments, subjects were instructed to listen to a pair of consecutive one kHz pure tones of 20 seconds duration. They were then asked to assess the relative loudness between the two presentations using a continuous scale from -50 to +50 (see Figure 1). A positive rating indicates that the second presentation is louder than the first presentation and a zero rating indicates equal loudness. The two pure tones were presented via a pair of bone vibrator (Viennatone 90AN, model 145-158-2/2L) and a pair head phone (Vega Mono Wire) respectively. The sound levels used were set according to the experimental conditions. Contact force between the bone vibrator and the mastoid was measured using a UPEX2 system (Ergonomic Concepts Ltd.) force sensor module. The experimental set up is shown in Figure 2. Only the left arm of the bone vibrator was used during the study investigating the effects of contact force.

1st presentation is	Equal loudness	2nd presentation is
Much louder		**Much louder**
!---------------------------------------	0	---------------------------------------!
(-50)	(0)	(+50)

Figure 1. Subjective rating scale for loudness comparison between two consecutive signals (subjects were asked to mark on the scale).

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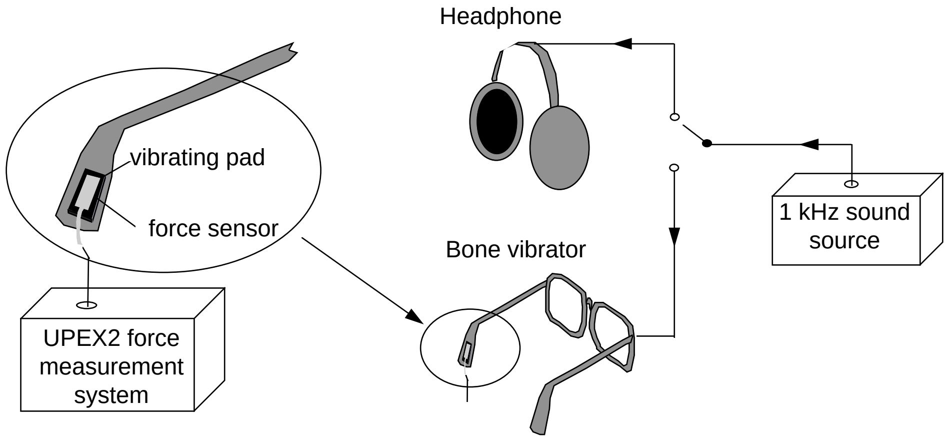

Figure 2. Experimental set up

Method and design

The same six subjects participated the three experiments. They were university students with normal hearing. Their ages ranged from 21 to 24. All subjects were restricted to male Chinese because Roysters *et. al* (1980) reported that race and gender could influence hearing levels.

The independent variables investigated included: eight repeated runs, two orders of presenting the pair of pure tones (bone vibrator first and head phone first), and six static contact forces between the bone vibrator and the mastoid (0.1N to 3.6N).

For the 'effects of practice' experiment, subjects first listened to a pure tone presented from the bone vibrator and then a second pure tone presented from the headphone. They were asked to rate the relative loudness between the two presentations. This was repeated eight times. The levels of tones were arbitrarily chosen by the experimenter.

For the 'effects of presentation order' experiment, subjects listened to three pairs of consecutive pure tones, in two different orders: bone vibrator first and headphone first. This formed six conditions and the sequences of presenting these conditions to the six subjects were assigned according to a 6x6 Latin square design. The volume levels of the three pairs of tone presentations were chosen arbitrarily by the experimenters. Each condition was repeated three times.

For the 'effects of contact force' experiment, subjects listened to six pairs of pure tones presented only by bone vibrators. The levels of all twelve presentations were the same although different static contact forces were applied between the bone vibrator and the mastoid. The first pure tone of each pair was presented with a static contact force of 0.1N while the second pure tones were presented with six different static contact forces. The sequences of presenting the six pairs of pure tones among the six subjects were balanced with a 6x6 Latin square design. ISO 389-3 (1994) recommends a 5.4N static contact force to be used with bone vibrators. This level was also used in some published studies with bone conduction (e.g. Haughton and Pardoe, 1981; Richter and Brinkmann, 1981). However, a 5.4N force was thought to be quite high and might cause dis-comfort if the bone vibrator was to be worn for more than one hour. A preliminary test had shown that the contact force of wearing the Viennatone 90AN bone conductor spectacle ranged from 0.05N to 0.5N depending on the size of the head

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(Jack and So, 1996). Therefore, the ranges of forces used in this experiment were chosen to be 0.1, 0.7, 1.8, 2.4, 3, and 3.6N.

Results and discussion

Effects of practice

The loudness comparison ratings are shown as functions of practices (Figure 3). Friedmann two-way analysis of variance has indicated that the practices had no significant effect on the loudness comparison ratings (p>0.5). Inspections of Figure 3 suggest that the inter-quartile ranges were approximately constant during the first four practices and then increased with further practices. This dis-agrees with the hypothesis that practices would reduce the inter-quartile range. One possible reason for the increase in inter-quartile range was that the subjects lost their concentrations after four practices.

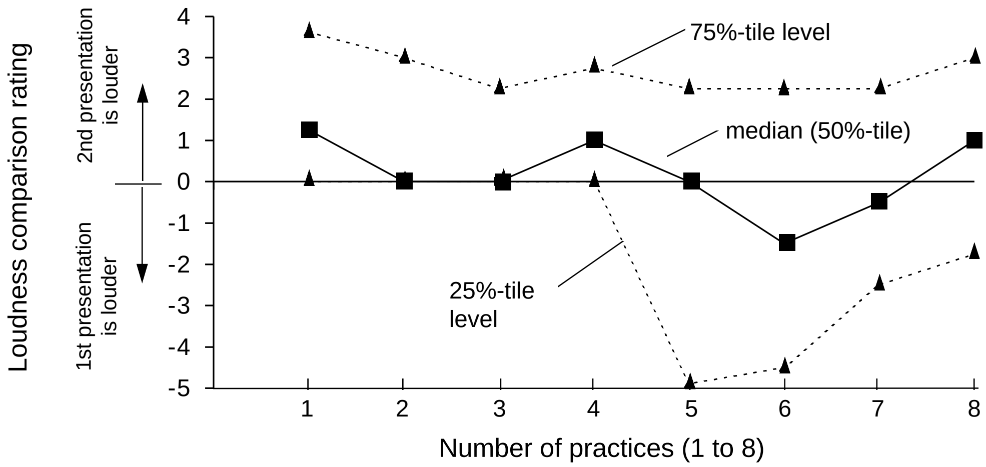

Figure 3. Loudness comparison ratings between two consecutive 1k Hz tones as functions of practices (a -ve rating indicates that the 1st tone was louder).

Effects of presentation order

Three pairs of 1kHz pure tones with different sound levels were used in this experiment (pair A, B, and C, Figure 4). Each pair consisted of a pure tone presented from a bone vibrator and a pure tone presented from a headphone. The effects of presenting the tone from the bone vibrator first or the tone from the headphone first were investigated. Loudness comparison ratings of the three pairs of pure tones with two presentation orders are shown in Figure 4. Each condition was repeated three times, and the results shown were the median across of the 6 subjects' data with the three repetitions (see last section for the effects of practices). Inspection of the figure shows that the loudness comparison ratings changed sign when the order of presentation was changed. This seems logical. Wilcoxon matched-pair signed ranked tests were performed to compare the absolute magnitude of the ratings with different presentation

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orders. Results of the tests indicated that the absolute values of the ratings were not significantly affected by the switching of presentation order (p>0.1).

Effects of static contact force

The loudness comparison ratings between a pair of 1k Hz pure tones presented via the same bone vibrator with different static contact force are shown in Figure 5. A 0.1N force was used in the first presentation while the contact forces used in the second presentation ranged from 0.1N to 3.6N. Inspection of Figure 5 shows that as the contact force of the 2nd presentation increased, the perceived loudness of the 2nd presentation decreased. Results of Friedmann two-way analysis of variance indicated that the ratings were significantly affected by the contact forces (p<0.002). It can be observed from the figure that the rating peaked at 0.7N although the differences between the ratings at 0.1N and 0.7N were not significant (p>0.5, Wilcoxon matched-pair signed ranked test). As the force increased to 1.8N and beyond, the sound transmitted via a bone vibrator reduced and the reduction became significant at 3.6N (p<0.01, Wilcoxon matched pair signed ranked test performed to compare the ratings at 0.1N and 3.6N). It is worth noting that the 0.7N level is much lower than the 5.4N static force recommended by the ISO 389-3 (1994). Further research is needed to confirm the relationship between the static contact force and the loudness of a bone vibrator.

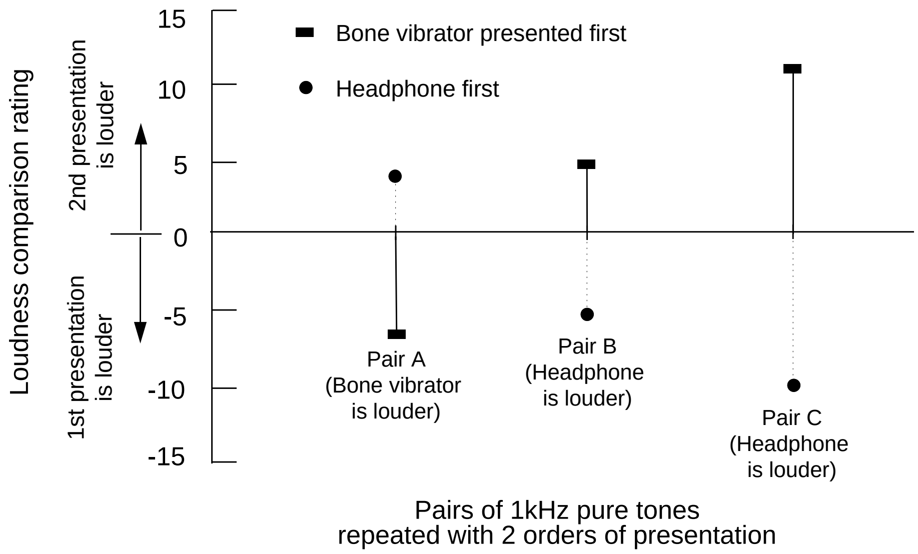

Figure 4. Loudness comparison ratings of three pairs of 1kHz tones presented consecutively via a bone vibrator and a headphone. The comparisons were repeated with 2 orders of presentation: bone vibrator first and headphone first. (A -ve rating indicates that the 1st presentation was louder). Data shown are median of 6 subjects with 3 repetitions.

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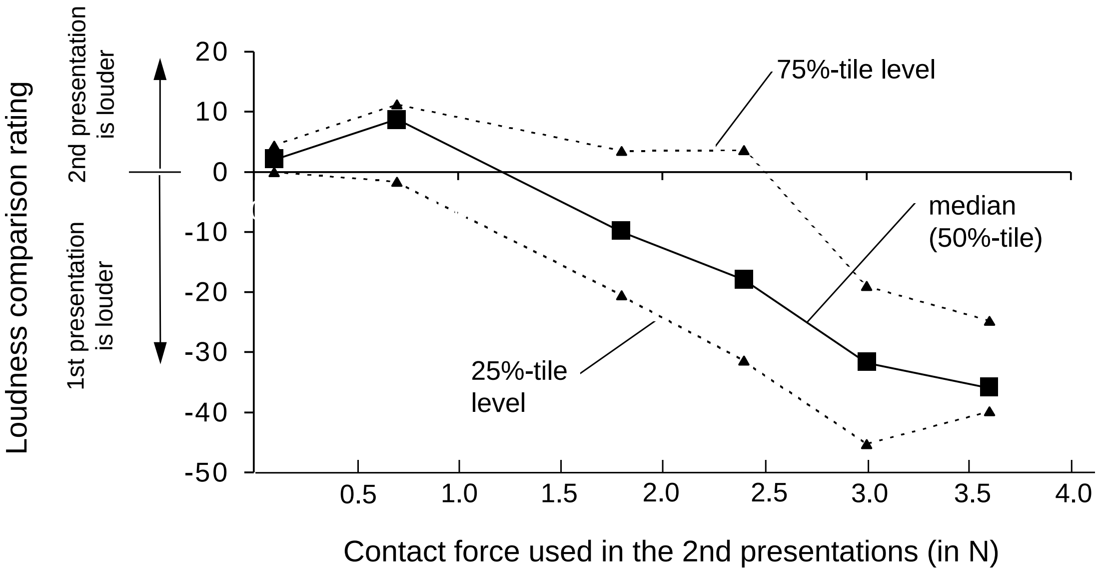

Figure 5. Loudness comparison ratings between two 1kHz tones of equal volume applied with the same bone vibrator but with different static contact force. The force used in the 1st presentation was 0.1N and the forces used in the 2nd presentation are shown. Median and inter-quartile range of 6 subjects' data are shown.

Conclusions

With eight consecutive practices, no significant trend was found in the subjective loudness comparison ratings between a pair of 1k Hz tones. However, there was a slight observable trend for the inter-quartile variability to increase after four repetitions. When comparing the loudness between two consecutive presentations of twenty seconds duration, switching the order of presentation would not introduce any bias in the comparison results.

When the static contact forces increased from 0.1N to 3.6N, the loudness rating of sound transmitted from a bone vibrator peaked at 0.7N and then decreased with increasing force. As these results were obtained with only six subjects, further research to confirm the findings are desirable.

Acknowledgment

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