Study of Auditory Localization with a Wearable Microphone Belt Providing Haptic Feedback

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1 Introduction

Spatial orientation and navigation in our acoustic surroundings are known to rely on auditory localization abilities. The aim of our study is to examine the precision and accuracy of human auditory localization with the contribution of a haptic-coupled hearing assistive device called the SmartBelt [1]. We wish to determine whether this multi-microphone belt providing haptic feedback around the waist results in better sound source localization in normal-hearing participants with simulated visual and hearing losses. The results of the study will serve as a milestone for the fine-tuning and design of assistive hearing devices for guiding people with sensory deficits such as single-sided deafness, as well as dual visual and hearing impairments.

2 Method

Twenty normal-hearing adults (11 females, 19-46 years of age) participated in the study. They were blindfolded and wore an earplug in the right ear to simulate a dual sensory loss. All participants completed an auditory screening which included a visualization of the ear canal, tympanometry and a measure of audiometric hearing thresholds. Participants were retained if their ear canals were unoccluded with normal middle ear function, and audiometric thresholds were at or below 15 dBHL between 250 to 8000 Hz. The SmartBelt (as shown in figure 1) was then calibrated to the participants' waist size according to the previously described methodology [1].

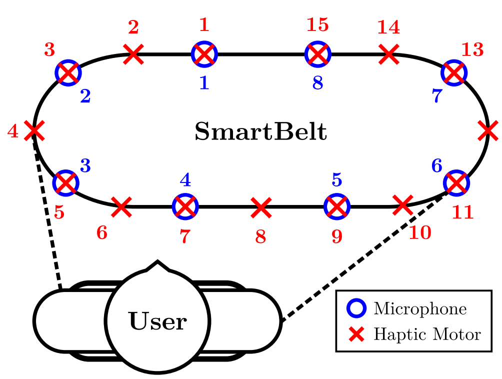

Figure 1 – Schema of the SmartBelt [1]

Participants underwent a training session prior to the localization task. The localization task took place in a sound booth with 20 loudspeakers surrounding the participants in a 360-degree circular array, named the Auditory Localization Evaluation System (SELA) [2] (see Figure 2). Participants wore a laser-helmet, aligned to their nose, to point to the angle of the loudspeaker, which was hidden behind a mesh curtain in the SELA. They were instructed to localize the sound source by turning their head and body to face the perceived location of the sound and pressing a button. An assistant inside of the booth read aloud the angle indicated by the participant. The stimulus was a 65 dBA, 3 second wide-band sound which simulated traffic noise on dry pavement. There were three test conditions corresponding to sections of the SELA array : frontal, right-side and left-side. Each condition contained 22 sound stimuli emitted by different loudspeakers in a randomized order. Participants wore the SmartBelt and each condition was tested twice with the device being either activated or deactivated. The six conditions were in randomized order and blind to the participants and assistant. Following the testing, participants completed the Quebec User Evaluation of Satisfaction with Assistive Technology (QUEST) questionnaire [3] to rate their experience with the SmartBelt.

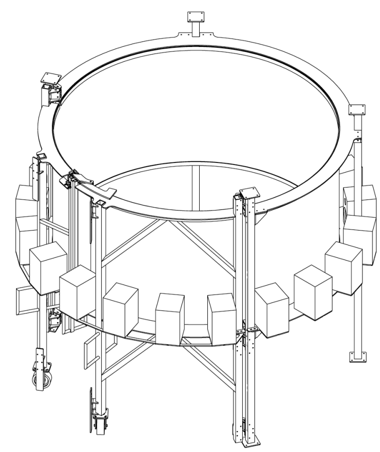

Figure 2 – The SELA sphere : a 20 loud-speaker system arranged 360° around the participant who is placed in the center of the sphere (image taken from the original manufacturing drawings, the 2006-2019 version was equipped with 11 loudspeakers).

3 Results

3.1 SELA

Localization performance within the SELA was defined as correctly identifying the source within 9 degrees of its actual location. Figure 3 shows there was a performance improvement when activating the SmartBelt in one out of the three conditions. Performance increased in the frontal condi-

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tion, however it worsened in the left-side condition. The right-side condition did not show significant changes when the belt was activated. A two-way analysis of variance (ANOVA) was conducted by condition (frontal, right-side, left-side), and activation (ON, OFF). It showed a significant effect of condition, $F(2,36) = 3.81, p = 0.03$, and a significant condition x activation interaction, $F(2,36) = 5.23, p = 0.01$. Paired t-tests revealed a significant difference between the activation and deactivation of the belt in the frontal ($p = 0.07$) and the left-side ($p = 0.05$) but not the right-side ($p = 0.70$) conditions.

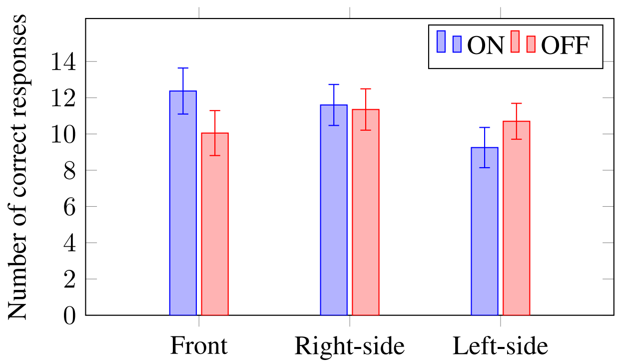

FIGURE 3 – Average score ($n = 20$) for participants using the SELA sphere. Brackets indicate standard error. There was a significant increase in correct responses for the frontal condition only when activating the belt. Right- and left-side conditions showed unchanged, and reduced performance, respectively.

3.2 QUEST Questionnaire

The QUEST questionnaire identified multiple advantages to wearing the belt : the training was simple and the effort was minimal to use the device efficiently. Functional performance of the device, which increases autonomy of the participant, also received high ratings. In contrast, appearance, practicality, and weight received lower ratings. Finally, the temporal characteristics of the haptic feedback (i.e. the timing occurring between the vibrotactile stimuli) as well as the positioning of the motors around the waist were determined as areas of improvement by most participants.

4 Discussion

This study demonstrates the effectiveness of using the SmartBelt, a vibrotactile technology that is activated in the direction of a sound source. The SmartBelt appears to increase the localization performance of individuals with a simulated dual sensory auditory and visual impairment when sounds occur in front of the user. The belt was not effective when the source of the sounds were located on either the left or right side.

The redundancy of the hearing and visual systems help provide complementary information about the sensory environment. When a person has a dual auditory/visual impairment, this redundancy is lost and localization performance will diminish [4]. Based on these results, compensating for this redundancy using a device-driven vibrotactile stimulation can compensate for the reduced audio-visual information. However it is still unknown whether this technology could be effective in the presence of competing noise, which is more likely what a user would encounter in a real-world environment. Future studies on the efficacy of the belt in the presence of non-target background noise, would be necessary for better external validation of this technology.

The reduced efficacy of the localization performance on the left or right sides may be due to the sub-optimal positioning of the haptic motors around the the user's waist. One example of a new distribution of the motors would be to remove the belt buckle and to place a motor at all four cardinal points (ex. 0°, 90°, 180° and 270°) specifically fit to each user. This may better aid the participant to map the sound source to the body. Another modification could be to reduce the size of the backpack so that the system is more aesthetically pleasing and comfortable.

Vibrotactile technology such as the SmartBelt may be an additional assistive technology for the improvement of auditory localization. Those who present poor auditory localization such as in those with dual sensory loss, are typically treated with amplification technology and auditory rehabilitation. This technology offers a new approach if current practices are insufficient to return auditory localization to normal limits.

5 Conclusions

The SmartBelt combines the use of auditory and haptic feedback to improve frontal localization. These findings suggest this vibrotactile device may benefit the localization abilities of those with dual sensory loss. Haptic-coupled hearing devices are a promising yet challenging domain of investigation today. Research in auditory localization with haptic feedback must be pursued to find appropriate and effective technical hybridizations and configurations (especially in terms of body placement and sensitivity) that take the perceptual experience of people with sensory impairments into account.

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