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Comparison of Localization Performance of Blind and Sighted Subjects on a Virtual Audio Display and in Real-life Environments

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ABSTRACT

Localization performance of blind subjects was measured in a virtual audio environment using non-individualized but customized HRTFs. Results were compared with former results of sighted users using the same measurement setup. Furthermore, orientation and navigation tasks in a real-life outdoor environment were performed in order to compare localization ability of sighted and visually impaired including "walking straight" tasks with and without acoustic feedback and test runs using the white cane as an acoustic tool during navigation.

1. INTRODUCTION

Several studies analyzed already different aspects of localization behavior, spatial hearing and navigation strategies of the visually impaired both in virtual and real-life environments [1-13]. In everyday life we rely on the “fact” that blind people can hear better, without thinking of what “better” means. Localization performance depends on many parameters such as properties of the excitation signal, environmental conditions, individual aspects or visual influence [14-16]. One of our goals was to create a virtual environment aimed at helping the blind community use personal computers. Developing this environment we were concerned to cover technical and hearing related questions, as well as human factors. In the second part, participants moved and navigated through an unfamiliar outdoor environment to test the veering effect of blind and blindfolded sighted subjects. The experimental setup was installed in an outdoor environment (handball court) to test the influence of auditory beacon signals (targeting a sound source) on the ability of keeping a 40-meter straight walking path. Finally, the use of the white cane as an acoustic tool was investigated. The task was to detect a corner based on wall reflections by knocking on the ground but not touching the wall.

2. VIRTUAL LOCALIZATION

For virtual localization tests a playback system was installed into the anechoic chamber [17-23]. It included the BEACHTRON sound card, customized human HRTFs and different localization tasks. 72 measured HRTFs were available in a form of 75-point minimum-phase-FIR-filter set in 30° spatial resolution. Missing directions are calculated by linear interpolation from the four nearest available measured directions and all subjects used the same HRTF set during the measurement. Results of 28 blind and 40 sighted participants were compared.

First, a 300 ms white noise burst had to be localized in an absolute localization task. A static sound source was emulated in front and back of the listener to test front-back reversals and in-the-head localization. Following this, a moving sound source around the head had to be identified (direction of circling) as well as movements of the sound source up and down in the median plane.

This was followed by a Minimum-Audible-Angle (MAA) discrimination task including two of the 300 ms white noise burst separated with silence. MAA values were determined in case of a moving source left, right, up and down compared to a static source in the origin in front of the listener. Novelties and general conditions in this MAA-measurement were:

- The use of a 2D virtual sound screen in the front of the listener. Sources could move only in the horizontal (left and right) and in the median plane (up and down) from the origin in 1° steps. This resulted in the source distances not being constant and the sources not appearing to move around the head.
- Subjects had to report in a 3-category-choice: "no difference between the sources", "different sound sources" and "I'm not sure". Subjects had the possibility to be uncertain about their sensation: if sound sources seemed to be completely identical or completely different, they selected one of the first two options, in any other cases they were uncertain.
- Burst-pairs had to be discriminated (a) as the second source is moving away from the static reference source, then (b) as it moves toward the reference point. We were looking for the nearest point to the reference, from the subject is able to discriminate the sources with certainty from both directions. If we determine the localization blur from both direction of moving, we will get a direction-independent localization performance.

Finally, a sound source discrimination task was conducted on a 3x3 grid in a 2D VAD (Fig. 1.).

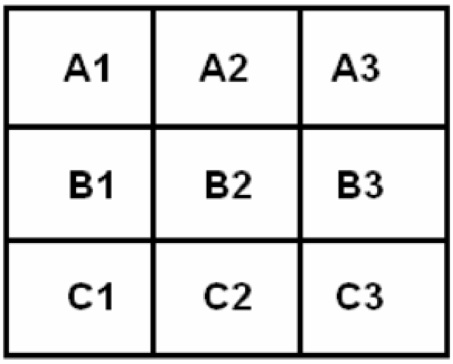

Figure 1. Spatial resolution of a 2D virtual audio display in a 3x3 grid in front of the listener. Subjects indicate fields by letter and number.

Based on F-tests there was no difference between population variances. Due to relatively large sample sizes z-Tests and t-Tests could be used for testing the difference between population proportions (at significance level 0.05).

Blind subjects delivered better results on a 3x3 grid and by localizing static frontal sources. In case of moving sources they were more accurate by determining movements around the head. On the other hand, sighted participants performed better during listening to ascending movements in the median plane and by detecting sources in the back. Results of a MAA measurement in front of the listener and in-the-head localization rates are almost identical for both groups. Gender, age, having a musical background or even absolute pitch, nor the fact being born blind (late blind) influenced the results. Every significant difference for the benefit of the blind subjects originated in the lower number of front-back reversals rates that seemed to be determining detection and localization of sound sources virtually.

3. EFFECT OF AUDITORY FEEDBACK ON VEERING DURING BLINDFOLDED WALKING

An experimental setup was installed in an outdoor environment to test the influence of auditory beacon signals (targeting a sound source) on the ability of keeping a straight walking path of blindfolded sighted participants [24]. 120 participants' walking trajectories were recorded via GPS tracker and veering from the straight line was measured in space and time.

The experiment was carried out in a free outdoor environment, on a concrete-surface handball court of 40-meters × 20-meters. The starting point was the base line (goal line) in the symmetry axis of the court and the target was the other base line 40-m ahead. There were no reflecting surfaces, buildings near the court. A GPS tracker was used for recording time, distances and walking trajectories. Good weather conditions were also a requirement, mostly sunny or cloudy days without wind. Test signals were white noise and 1 kHz click-train. The latter is a looped 200-ms 1 kHz sinusoidal burst followed by a 200-ms silence. These signals were played back on a Discman in CD quality, amplified and radiated by a loudspeaker standing in the target position at 1,1 meters height. Sound pressure level of the sound source was 90 dB at 6-meter distance.

The experiment was conducted as follows. After registering personal data a detailed explanation of the procedure was given. Subjects held the GPS tracker in the hand and faced the target. Without any auditory feedback they tried to walk blindfolded toward it with the experimenter behind them to avoid any damages or injuries. The waking ended if the subject reached the other goal line (in ideal case the target) or walked off the court on the sides. The next run included the same task but with the auditory target active: first the click train, followed by the white noise signal. At the end, the first run without sound was repeated to check whether any learning or adaptation processes are present or not.

To this point 120 sighted and 20 blind participated. Results showed that missing external reference results in veering shortly after couple of meters, supporting former results. 17% of the sighted participants could reach or were within ±1 meter without using external auditory cues. There were no side preferences for veering and trajectories showed an almost symmetrical spatial distribution to the straight walking path (Fig. 2). Blind subjects were somewhat slower in this task (4-6 seconds). Mean errors in meters and veering suggest no significant difference between the groups without acoustic feedback.

Furthermore, simple auditory beacon signals, such as clicks and broadband noise can serve as external reference, resulting in that almost all participants were able to approach the sound source without serious veering based on sound source localization (96-97%). Figure 3 shows the trajectories in case of a white noise reference. We had only one subject in both groups who could not reach the target because of hearing damage. Almost the same results can be obtained using the click-train signal, however, participants preferred the white noise excitation.

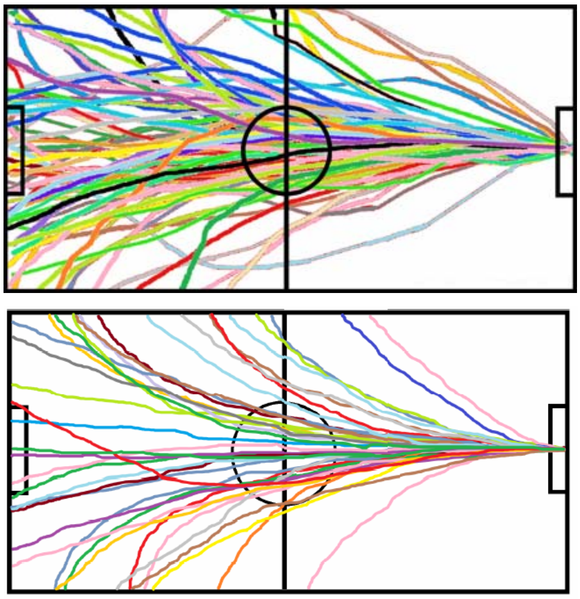

Figure 2. Walking trajectories based on GPS tracking during the first try without sound for 120 blindfolded sighted (top) and 20 blind subjects (bottom).

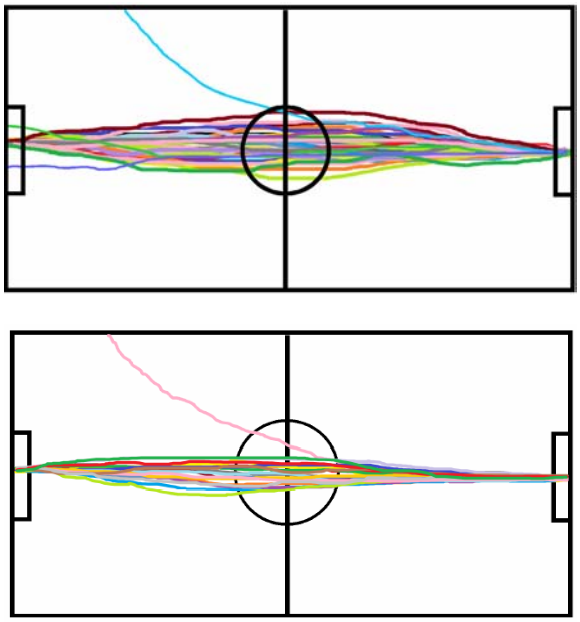

Figure 3. Walking trajectories based on GPS tracking in case of white noise excitation for 120 blindfolded sighted (top) and 20 blind subjects (bottom).

Current research work includes recruiting more blind subjects to increase statistical significance and analysis of the obtained results based on single and paired t-Tests.

4. USING THE WHITE CANE AS AN ACOUSTIC TOOL

For the visually impaired are auditory cues, tactile perception and fragments of the visual perception the most important. During navigation tasks, the direct and reverberant acoustic energy serves for spatial information about the environment. Spatial information includes directional information (localization) and distance, as well as detecting existing objects ("obstacle sense"). For this, echolocation can be used from external sound sources (traffic noise, sound of the objects etc.) as well as sounds created by the blind (e.g. the white cane). Objects and obstacles can be classified as follows:

- objects radiating sound (people, cars, telephone etc.),
- silent objects (walls, corners, door openings etc.).

The localization of silent objects can be made based on echolocation. Human echolocation is the ability of humans to detect objects in their environment by sensing echoes from those objects. By actively creating sounds – for example, by tapping their canes, lightly stomping their foot or making clicking noises with their mouths – people trained to orientate with echolocation can interpret the sound waves reflected by nearby objects, accurately identifying their location and maybe size. This ability is used by some blind people for acoustic wayfinding, or navigating within their environment using auditory rather than visual cues. Some can also identify shape and texture of objects based on this information. The most important tool for that can be the white cane, however, the primary goal of it is to avoid collision with obstacles (below the waistline) rather than using it as an acoustic tool.

In order to test the ability of blind and blindfolded sighted people in echolocation, an outdoor experiment was performed using the white cane as a tapping device. The task was to walk on a short distance (couple of meters) parallel to a concrete wall (Fig. 4). Users were able to tap the concrete sidewalk as long and as often they wanted to. They could walk back and forth as well and they had to stop where they thought the wall ended (corner detection). Other parameters, such as changes in the material of the pathway, changes in light or temperature (Sun), wind, external traffic noise etc. were eliminated. In case the subject walked off the sidewalk, touched the wall etc. the experiment was repeated. To this point of the experiment, 70 sighted and 22 visually impaired participated (19-63 years of age).

Figure 4. Blindfolded subject during the experiment to detect the corner by tapping with the white cane.

Results were recorded in meters, where the origin corresponds to the corner (Fig. 4). Differences were measured in both directions as signed error values. Figure 5 shows results for blindfolded sighted users within ±2 meters from the corner. Figure 6 shows the same for blind participants.

Results of blindfolded sighted were mostly within ±1 meter. Blind users do tend to be better in this task, they almost never stopped before the corner and most of them were within 0,5 meters (Tables 1-2). A preliminary comparison was also made between the first run and a second run for both groups.

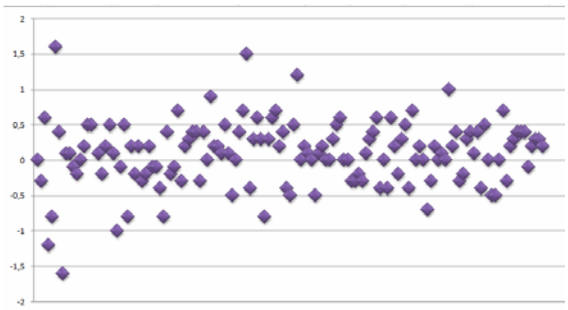

Figure 5. Individual results of 70 blindfolded sighted subjects during corner detection.

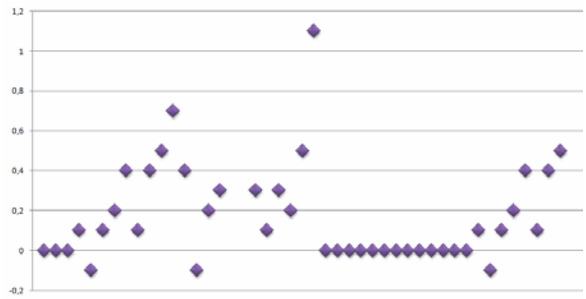

Figure 6. Individual results of 22 blind participants during corner detection.

%	Corner (0 m)	more than 0,5 m	less than 0,5 m	0-0,5m	0--0,5m
Blind	36	14	0	43	7
Sighted	13	17	9	38	22

Table 1. Relative number of participants stopping at the corner, more or less than 0,5 m and within ±0,5 m.

[m]	Differences (sighted)	Differences (blind)
Maximum	1,6	1,1
Minimum	-1,6	-0,1
Mean	-0,09	0,18
Standard dev.	0,46	0,25

Table 2. Maximum, minimum and mean values of differences in results of blind and sighted participants.

It is sometimes suggested that results are influenced by the fact, how long the blind subject has been already blind (so called early blind, late blind) [1-3]. Late blinds who lost their vision more than 30 years ago performed better in tasks using the white cane as an acoustic tool.
The median of the results shows where half of the results are below and the other half above this value. In this case, the median was not the corner, but 0,1 meters farther from it for both groups. Nevertheless, the median was different for the first and the second run. Figures 7 and 8 show differences for the same group between the first and the second run. No clear pattern can be recognized and further statistical analysis (such as paired t-Test) is required. Calculated correlation values between the first and second run were -0,05 meters for the sighted and 0,7 meters for the blind indicating almost complete independence from the trial runs among sighted participants.
The mode of the results shows the distance where they stopped the most frequently. It was 0,2 meters for the sighted and 0 (the corner) for the blind. Table 3 shows it detailed for the first and second run.

	Median [m]		Mode [m]		Correlation	
	B	S	B	S	B	S
1. run	0,05	0,05	0	0		
2. run	0,1	0,2	0	0,4		
Sum	0,1	0,1	0	0,2	0,7	-0,05

Table 3. Median, Mode and Correlation in results for the first and second run of the experiment for blind (B) and sighted (S) participants.

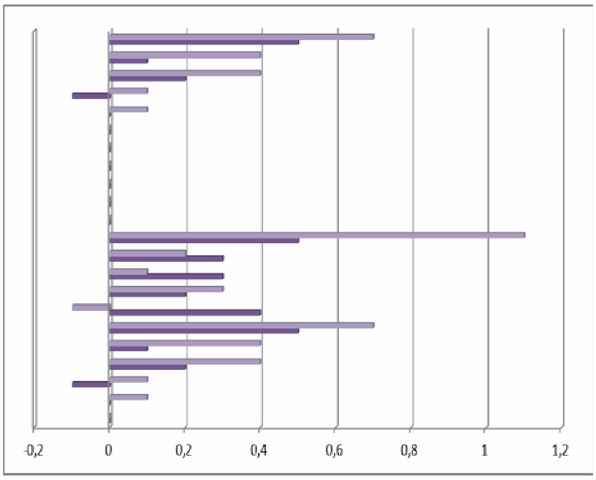

Figure 7. Results of blind participants during the first (dark color) and the second run (light color).

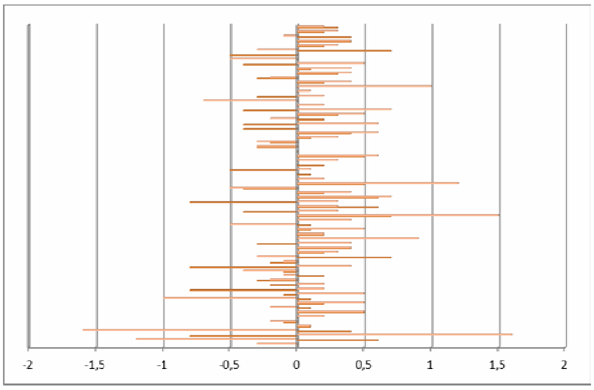

Figure 8. Results of sighted participants during the first (dark color) and the second run (light color).

5. SUMMARY

Localization and orientation tasks were performed in a comparative experiment between blind and blindfolded sighted subjects. First, virtual localization tasks had to be solved using customized HRTFs and headphone playback. Blind subjects performed at least as well as sighted subjects did, mostly due to less front-back errors. Second, veering effects were tested during a "walking straight" navigation task with and without auditory beacon signals. Both group tended to veer without acoustic feedback and succeeded to walk straight in presence of external auditory stimuli. Finally, the role of the white cane as an acoustic tool was tested during detecting walls and corners based on sound reflections (echolocation). In this task, blind persons performed better than blindfolded sighted. Future work includes involving more subjects, listening tests in the anechoic chamber and statistical analysis.

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