787.14 A comparison of free-field and headphone based sound localization using SoLoArc: A modular, portable, audiovisual, free-field localization device with high spatial resolution

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Westerberg, J.A.[1,2], Balhorn, A.R.[1,3], Tyshynsky, R.S.[1,3], & Loebach, J.L.[1,4]

[1]Neuroscience Program; [2]Center for Integrative Studies; [3]Biology Department; [4]Psychology Department

St. Olaf College, Northfield, MN, USA

SCog Lab
Speech and Cognition Lab

Introduction

Sound localization is often demonstrated in undergraduate classrooms and labs using artificial binaural ITD and ILD cues presented over headphones. Such tasks can be confusing, difficult for undergraduates to administer and interpret, and prone to experimental errors. Free-field tasks can be difficult to standardize across individuals, and precision can vary from group to group. Over the past 8 months we have designed and fabricated a portable audiovisual localization device. Here, we describe the construction of the SoLoArc, and present data from 3 studies, demonstrating that the device works as intended, and produces more accurate localization in the free-field azimuth compared to ILD and ITD cues presented over headphones.

The device presents auditory stimuli in a 180° arc from speakers placed every 5° on the concave surface. A participant is seated at the point of convergence of the sound field, 4 feet from each speaker. An array of 73 LEDs allows the investigation of visual influence in localization tasks. The arc can be positioned for azimuth, front/back, or vertical localization. The participant's head may be fixed or freely moving. The device is interfaced to a PC using 2, 96-channel NI USB I/O devices. Matlab is used for device control allowing stimuli of any frequency and intensity to be created and delivered from each speaker independently.

Methods

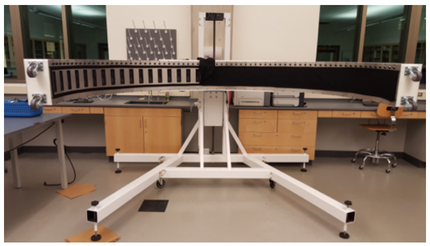


Figure 1: SoLoArc Apparatus
The SoLoArc can present sound from one of 37 auditory sources in 5° increments, and 73 visual sources in 2.5° increments in a 4-foot radius arc. Acoustically permeable fabric obscures the subject's view of the individual audio sources without influencing sound. Audio and visual stimuli may be presented simultaneously, separately, or concurrently with adjustable delay.

Participants

- 28 St. Olaf College Students enrolled in a Sensation and Perception course

Headphone based task using ITDs as primary signal:

- 440 Hz sinusoids presented to participants via stereo headphones with interaural delays of 640 μsec (right ear lead) to -640 μsec (left ear lead)
- Source locations were chosen from one of four randomized lists
- Subjects indicated estimated angle via a printed map of space

Headphone based task using ILDs as primary signal:

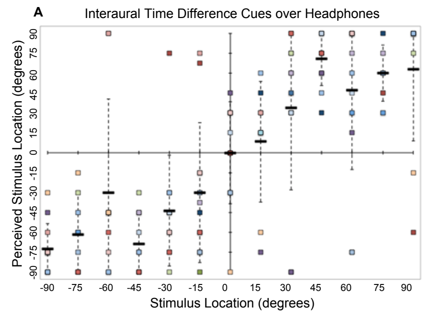
- 6000 Hz sinusoids presented via stereo headphones with intensities of +/- 21 dBA SPL between right and left ears
- Source locations were chosen from one of four randomized lists
- Subjects indicated estimated angle via a printed map of space

Free-Field localization using the SoLoArc:

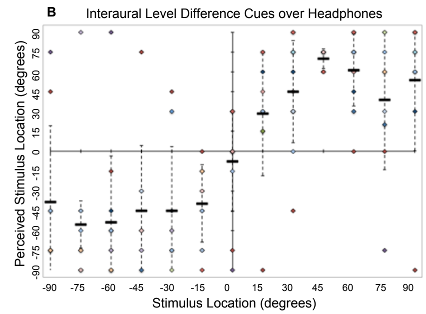
- Participant centered under SoloArc, stabilized with contoured pillow with unobstructed pinnae equidistant from speakers at -90 and +90 degrees
- Completed one of 8 predefined sets of 26 trials
- Each trial began with 3 seconds of silence, followed by 1000 Hz tone at 70 dBA SPL for 0.5 seconds
- Indicated perceived location on SoLoArc with a laser pointer which was recorded manually by an experimenter
- No limit on trial repeats
- Data compiled and analyzed in Microsoft Office Excel and SPSS

Results

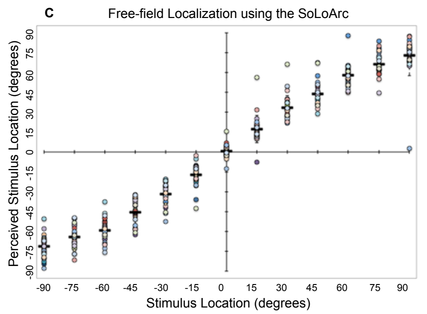
Figure 2. Comparison of stimulus location versus perceived location via headphone and free-field presentation Graphs A, B, and C show error for each method of stimulus presentation. Graph D compares the average error in localization for each method of stimulus presentation.



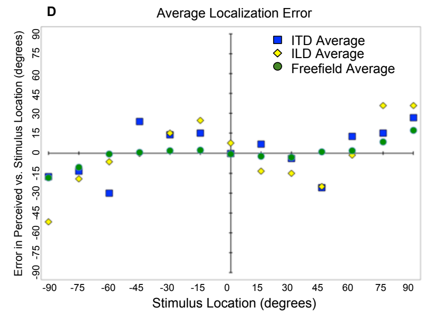
Angular location of sound source by participants (y-axis) as a function of actual stimulus presentation location (x-axis) based on interaural time differences. Colored squares indicate the responses of individual participants. Black horizontal lines represent the average for each angle, and error bars are the standard error of the mean. A linear regression analysis revealed significant correlations between the ITD estimates and the ideal (R^2=.891, $F(1,12)$=98.924, p<0.001), and Beta weights (B=.858, t=9.946, p < 0.001).



Angular location of sound source by participants (y-axis) as a function of actual stimulus presentation location (x-axis) based on interaural level differences. Colored diamonds indicate the responses of individual participants. Black horizontal lines represent the average for each angle, and error bars are the standard error of the mean. A linear regression analysis revealed significant correlations between the ITD estimates and the ideal (R^2=.802, $F(1,12)$=49.606, p<0.001), and Beta weights (B=.762, t=7.043, p < 0.001).



Angular location of sound source by participants (y-axis) as a function of actual stimulus presentation location (x-axis) based on free field presentation. Colored circles indicate the responses of individual participants. Black horizontal lines represent the average for each angle, and error bars are the standard error of the mean. A linear regression analysis revealed significant correlations between the ITD estimates and the ideal (R^2=.989, $F(1,12)$=1047.901, p<0.001), and Beta weights (B=. 887, t=32.371, p < 0.001).



Average deviation (y-axis), obtained by subtracting the perceived angular location of the sound source from the actual location (x-axis). Blue squares are average deviations for ITD cues presented over headphones, Yellow diamonds, ILD cues presented over headphones, and green circles are free field presentations using the SoLoArc. Deviations closer to zero indicate more accurate performance.

Acknowledgements

We would like to thank the following groups and individuals for their support and contributions to our research: Faculty for Undergraduate Neuroscience Student Travel Award; Grass Foundation; Collaborative Undergraduate Research Initiative, St. Olaf College; Department of Psychology, St. Olaf College; Faculty of the Natural Sciences and Mathematics, St. Olaf College; Devin Lackie, Department of Physics, St. Olaf College; Vanessa Balhorn and her sewing machine.

Discussion

The purpose of this study was threefold:

1. To compare sound localization accuracy using three different methods: synthetic interaural time difference cues presented over stereo headphones, synthetic interaural level difference cues presented over stereo headphones, and pure tone sound localization in the free field using the SoLoArc.

2. To determine whether the SoLoArc, a custom designed and built apparatus, functions properly and provides at least a comparable level of accuracy to other methods of assessing sound localization.

3. To assess the utility of the SoLoArc in the undergraduate classroom.

In response to our first purpose, we demonstrated that the SoLoArc produced free-field sound localization that was superior to sound localization using synthetic ITD and ILD cues presented over stereo headphones. Significant variability can be seen in the synthetic measurements, with some participants, although given basic instruction on the task, responding in the rear plane. Higher significant correlations and beta weights further demonstrate that the SoLoArc provided a better fit to the idealized localization compared to the synthetic methods.

In response to our second purpose, as designed, the SoLoArc is functional, though a few minor modifications may be required to achieve its full potential.

In response to our third purpose, we demonstrated that the SoLoArc appears appropriate for use in the undergraduate classroom and laboratory. Students from the Sensation and Perception course found the device itself to be far more intuitive, tasks easier to understand, and sound sources easier to localize using the SoLoArc compared to the synthetic conditions.

Finally, one unique aspect of our approach was to put the creation of the device itself in the hands of the students. A true collaboration between students, faculty and staff, provided an eight-month experience in experimental apparatus design, engineering, and fabrication. While such a pedagogical approach is often overlooked in the undergraduate curriculum, it can be an important part of teaching the scientific process. Not all instrumentation is available for off the shelf purchase, and a fundamental understanding of the tools of inquiry may serve future scientists better than building the device for them. Please see our theme H poster number 24.04AS for more information on the build itself.

Future Directions

With the functionality of the SoLoArc being established, a number of uses for the device have been identified. The durability of the apparatus will allow for additional research opportunities for students and faculty alike for years to come, including use in student independent research, within laboratory courses at St. Olaf College, and for faculty research on localization in cochlear implant users in the St. Olaf ScogLab.

- **Pinna modification:** The initial interest in building the device stemmed from a desire to better understand the role of the external ear in vertical sound localization. Thus we will be temporarily modifying participants' pinnae and use eye tracking to to determine their estimated source localization.
- **Hemodynamic measures of cognition:** Currently, we are using the SoloArc to present stimuli in an audiovisual choice-countermanding task in order to compare the activity in the frontal eye fields using functional near-infrared spectroscopy under varying conditions of auidovisual cognitive load.
- **Application to cochlear implant research:** Understanding sound localization has been an area of interest recently due to the number of CI users with bilateral implants. The SoLoArc now allows the ScogLab to expand its cochlear implant research into the sound localization domain.
- **Utility in courses:** The SoLoArc provides the physical means to develop and demonstrate free-field principles in a fun and intuitive manner. Students from an array of courses will be able to learn from and interact with SoLoArc.

References

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