

Submission ID #: 70048

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Title: An Automated System for Sound Localization Testing in Hearing-Impaired Listeners

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Author Questionnaire

1. Microscopy: Does your protocol require the use of a dissecting or stereomicroscope for performing a complex dissection, microinjection technique, or something similar? **No**

2. Software: Does the part of your protocol being filmed include step-by-step descriptions of software usage? **Yes, all done**

~~Videographer: Please record the computer screen for the shots labeled as SCREEN as back-up~~

3. Filming location: Will the filming need to take place in multiple locations? **No**

4. Testimonials (optional): Would you be open to filming two short testimonial statements **live during your JoVE shoot**? These will **not appear in your JoVE video** but may be used in JoVE's promotional materials. **No**

Current Protocol Length

Number of Steps: 14

Number of Shots: 40 (17 SC)

Introduction

Videographer: Obtain headshots for all authors available at the filming location.

Authors: Please note that **the questions will not appear on screen**. Please answer in **stand-alone full sentence with sufficient context**.

Answers are slightly edited in accordance with the journal guidelines

INTRODUCTION:

Author's NOTE: Please note that Hyo-Jeong is a hyphenated two-syllable given name, not a first and middle name. The full name Hyo-Jeong Lee should be used consistently

~~**REQUIRED:** Summarize your research focus and the main questions it aims to answer.~~

- 1.1. **Hyo-Jeong Lee:** In this study, we aim to develop a fully automated system to measure sound localization ability in patients with hearing impairment.
 - 1.1.1. INTERVIEW: Named talent says the statement above in an interview-style shot, looking slightly off-camera

~~**Describe the research gap or limitation in existing methods and how this protocol addresses them.**~~

- 1.2. **Hyo-Jeong Lee:** Although some systems include a certain level of automation, many sound localization tests still rely on examiner supervision and manual workflows. This protocol provides an end-to-end automated framework.
 - 1.2.1. INTERVIEW: Named talent says the statement above in an interview-style shot, looking slightly off-camera

CONCLUSION:

~~**What does this protocol allow researchers to study or measure?**~~

- 1.3. **Hyo-Jeong Lee:** This protocol allows researchers to measure sound localization performance using a standardized and automated testing system.
 - 1.3.1. INTERVIEW: Named talent says the statement above in an interview-style shot, looking slightly off-camera

~~**Describe the most important consideration or challenge when performing this protocol.**~~

1.4. **Hyo-Jeong Lee:** Maintaining a consistent head position during stimulus presentation is critical for obtaining accurate sound localization measurements.

1.4.1. INTERVIEW: Named talent says the statement above in an interview-style shot, looking slightly off-camera

~~How can future studies build on this work? Describe the questions or research directions that can be investigated next.~~

1.5. **Hyo-Jeong Lee:** Future studies can apply this protocol to compare spatial hearing outcomes across listener groups and clinical interventions.

1.5.1. INTERVIEW: Named talent says the statement above in an interview-style shot, looking slightly off-camera

Videographer: Obtain headshots for all authors available at the filming location.

Ethics Title Card

This research has been approved by the Institutional Review Board of Hallym University
Sacred Heart Hospital

Protocol

2. Equipment Setup and Calibration

Demonstrators: Seung-Ik Jeon, Gyung-Sik Jeon

Author's NOTE: Please note that the demonstrator's name should appear as Seung-Ik Jeon. The hyphenated given name and the same should be applied to Gyung-Sik Jeon

- 2.1. To begin, set up a soundproof booth with internal dimensions of approximately 3,800 by 2,200 by 2,100 millimeters to provide a controlled free-field listening environment [1] and install a semicircular loudspeaker rack with a radius of 3,000 millimeters inside the booth [2].
 - 2.1.1. WIDE: Talent pointing and showing the soundproof booth.
 - 2.1.2. Talent standing next to the rack and pointing to the semicircular loudspeaker rack.
- 2.2. Mount seven loudspeakers on the rack at 30-degree intervals spanning from minus 90 degrees to plus 90 degrees azimuth [1]. Position all loudspeakers at the same height of approximately 1,050 millimeters corresponding to head level when seated [2]. Place each loudspeaker at an equal distance from the participant's head [3].
 - 2.2.1. Talent showing seven loudspeakers kept evenly along the semicircular rack.
 - 2.2.2. Talent adjusting a loudspeaker. **Authors:** Simply act as if you are tilting and adjusting the speaker
 - 2.2.3. Talent measuring the distance between adjacent speakers with a tape.
- 2.3. Connect the loudspeakers to a multichannel audio interface using balanced, shielded XLR audio cables [1].
 - 2.3.1. Talent showing the XLR audio cables connected to the audio interface.
- 2.4. Control stimulus presentation and data acquisition using a Windows-based personal computer running custom-developed software [1].
 - 2.4.1. Talent turning on the computer.
- 2.5. For calibration, present a broadband noise stimulus that is root mean square matched to the test stimuli from each loudspeaker [2].

2.5.1. SCREEN: [13MAR26]-2.5.1.-BBnoise-played-for-calibration.mp4. *Videographer: Please record the computer screen for the shots labeled as SCREEN as back-up*

2.6. Place a Class 1 precision sound level meter equipped with a free-field microphone on a tripod at head level of approximately 1,050 millimeters at the participant position [1]. Measure the equivalent continuous sound level, defined as Z-weighted time-averaged sound pressure level, from each loudspeaker [2]. Adjust the output levels so that the measured equivalent continuous sound level is approximately 60 decibels sound pressure level across all loudspeakers [3].

2.6.1. Talent positioning the Class 1 precision sound level meter with free-field microphone on a tripod.

2.6.2. Shot of the sound level meter display showing the equivalent continuous sound level measurement during playback.

2.6.3. SCREEN: 2.6.1,-2.7.3-Calibration-screen.mp4 01:00-01:15.

2.7. Prepare a height-adjustable chair equipped with a headrest to stabilize the participant's head position during stimulus presentation [1]. Ensure the headrest provides tactile feedback to help maintain a consistent forward-facing head orientation during stimulus presentation [3].

2.7.1. Talent placing the height-adjustable chair with headrest at the center of the loudspeaker array.

2.7.2. Shot of participant seated with the headrest supporting the head in a forward-facing orientation.

3. Seating the Participant and Familiarization

3.1. Now, seat the participant on the custom-made chair so that the head aligns with the frontal loudspeaker at 0 degrees azimuth corresponding to the central position of the semicircular array [1]. Adjust the headrest to fit firmly against the occipital protuberance and instruct the participant to maintain contact with the headrest throughout the test [2]. Place a touchpad directly in front of the participant and provide instructions on its use to record responses [3].

3.1.1. Talent seating the participant at the center of the semicircular loudspeaker array, aligned with the frontal loudspeaker.

3.1.2. Talent adjusting the headrest against the occipital protuberance and confirming firm contact.

3.1.3. Talent placing a touchpad in front of the participant.

3.2. Now, enter the participant identification code and trial number into the graphical user interface [1]. Select the hearing-device status by choosing cochlear implant, hearing aid, or no hearing aid [2] and start the familiarization sequence by selecting the **Familiarization** button followed by **start** [3]. Instruct the participant to maintain gaze toward the central loudspeaker throughout the sequence [4]. Present auditory stimuli automatically and sequentially from each loudspeaker during the familiarization sequence [5].

3.2.1. SCREEN: 3.2.1,-3.2.2-participant-code,-trial-number-entering.mp4 00:07-00:17.

3.2.2. SCREEN: 3.2.1,-3.2.2-participant-code,-trial-number-entering.mp4 00:22-00:28.

3.2.3. SCREEN: 3.2.3,3.2.5-familiarization.mp4 00:00-00:10.

3.2.4. Shot of the participant maintaining gaze toward the central loudspeaker.

3.2.5. SCREEN: 3.2.3,3.2.5-familiarization.mp4 00:15-00:25.

4. Pre-Test Procedure

4.1. Select the **Pre-test** button on the graphical user interface to activate the pre-test mode [1]. Instruct the participant to face the frontal loudspeaker and maintain a forward head orientation [2]. Direct the participant to press the **Start** button on the touchpad when ready [3]. Upon pressing the Start button, present the first test sound from one of the loudspeakers [4]. After the sound presentation, switch the touchpad display to a loudspeaker map and record the participant's selection of the perceived sound-source location [5].

4.1.1. SCREEN: 4.1.1-selecting-pre-test.mp4.

4.1.2. Shot of the participant facing the frontal loudspeaker with a forward head orientation.

4.1.3. Shot of the participant pressing the Start button on the touchpad.

4.1.4. Shot of the participant making a selection of the source.

4.1.5. Participant selecting the perceived sound-source location directly on the touchpad.

- 4.2. Provide immediate feedback after each response. Display a confirmation message for correct responses before allowing progression to the next trial [1]. Highlight the correct loudspeaker location on the map for incorrect responses and replay the sound three times from that loudspeaker [2]. After the third trial, the pre-test is automatically terminated [3].

- 4.2.1. SCREEN: [13MAR26]-4.2.1.-loudspeaker-map-highlighting-the-correct-location.mp4.

- 4.2.2. Participant listening to the sound stimulus while maintaining forward head orientation.

- 4.2.3. SCREEN: 4.2.4.-automatic-termination-of-pre-test.mp4.

5. Main Test Procedure and Data Logging

- 5.1. After completion of the pre-test, select the **Main test** button on the graphical user interface to start the main test sequence [1]. Instruct the participant to press the **Start** button on the touchpad to trigger presentation of a sound from one of the loudspeakers [2]. Present the sound from one of the loudspeakers upon pressing the Start button [3]. After the sound presentation, switch the touchpad display to a loudspeaker map and record the participant's selection of the perceived sound location [4]. Following each response, the **Next** button is displayed on the screen [5].

- 5.1.1. SCREEN: 5.1.1-selecting-main-test-button.mp4.

- 5.1.2. Shot of the participant pressing the Start button on the touchpad.

- 5.1.3. Shot of participant paying attention to the sound and talent observing the participant's response.

- 5.1.4. SCREEN: 5.1.4.,-5.1.5.,-5.2.2.-Main-test-sequence.mp4. 00:00-00:04

- 5.1.5. SCREEN: 5.1.4.,-5.1.5.,-5.2.2.-Main-test-sequence.mp4. 00:04. *Video editor: Highlight the "Next" button*

- 5.2. Advance automatically through the predefined number of trials and repeat the trial sequence until the main test is completed [1].

- 5.2.1. SCREEN: 5.1.4.,-5.1.5.,-5.2.2.-Main-test-sequence.mp4. 00:05-00:13.

- 5.3. Let the system automatically terminate the session at the end and generate a CSV log file [1]. Record each trial in the log file including the stimulus presented, the direction of the sound source, and the participant's response [2]. Verify the calculated

localization performance metrics, including root mean square error, mean absolute error, and response bias, in the results sheet [3].

5.3.1. SCREEN: 5.3.1-automatic-termination-of-main-test.mp4.

5.3.2. SCREEN: 5.3.2.-log-file-for-each-trial.mp4 00:05-00:11.

5.3.3. SCREEN: 5.3.3-calculated-result.mp4. *Video editor: Please seed up*

Results

6. Results

- 6.1. A total of 34 participants were enrolled in this study, with 20 adults having normal hearing or NH and 14 adults with single-sided deafness or SSD [1]. A representative NH participant exhibited accurate localization overall, with responses aligned along the diagonal [2] and one error at minus 90 degrees [3].
 - 6.1.1. LAB MEDIA: Figure 4
 - 6.1.2. LAB MEDIA: Figure 4. *Video editor: Highlight the diagonal line formed by the bubbles from lower left to upper right*
 - 6.1.3. LAB MEDIA: Figure 4. *Video editor: Highlight the bubble at stimulus -90 on X-axis and at the -60 mark on Y-axis that does not fall on the diagonal*
- 6.2. The representative right-sided SSD participant exhibited low overall localization accuracy, with responses biased toward the intact left side across azimuths [1].
 - 6.2.1. LAB MEDIA: Figure 5. *Video editor: Highlight the all bubbles lower to the 0 mark on Y axis*
- 6.3. Using the ICF-based classification approach, most SSD participants were categorized as exhibiting moderate to severe impairment [1], with one case of complete impairment [2] and one case of no impairment [3].
 - 6.3.1. LAB MEDIA: Figure 6. *Video editor: Highlight the red dots within the shaded regions labelled "2: Moderate impairment" and "3: Severe impairment."*
 - 6.3.2. LAB MEDIA: Figure 6. *Video editor: Point to the red dot located in the top shaded region labelled "4: Complete impairment."*
 - 6.3.3. LAB MEDIA: Figure 6. *Video editor: Point to the red dot located in the bottom shaded region labelled "0: No impairment."*
- 6.4. In contrast, the NH group was mostly classified as having no impairment [1], except for one participant who showed mild impairment [2].
 - 6.4.1. LAB MEDIA: Figure 6. *Video editor: Highlight the blue dots within the shaded region labelled "0: No impairment."*
 - 6.4.2. LAB MEDIA: Figure 6. *Video editor: Point to the single blue dot located in the shaded region labelled "1: Mild impairment."*

1. Soundproof
Pronunciation link: <https://www.merriam-webster.com/dictionary/soundproof>
IPA: /'saʊndˌpruːf/
Phonetic Spelling: sound·proof
2. Semicircular
Pronunciation link: <https://www.merriam-webster.com/dictionary/semicircular>
IPA: /ˌse.mi'sɜː.kjə.lə/
Phonetic Spelling: sem·ee·ser·kyuh·ler
3. Azimuth
Pronunciation link: <https://www.merriam-webster.com/dictionary/azimuth>
IPA: /'æz.ə.məθ/
Phonetic Spelling: az·uh·muth
4. Multichannel
Pronunciation link: <https://www.merriam-webster.com/dictionary/multichannel>
IPA: /ˌmʌl.ti'tʃæn.əl/
Phonetic Spelling: mul·tee·chan·uhl
5. Calibration
Pronunciation link: <https://www.merriam-webster.com/dictionary/calibration>
IPA: /ˌkæl.ə'breɪ.fən/
Phonetic Spelling: kal·uh·bray·shuhn
6. Broadband
Pronunciation link: <https://www.merriam-webster.com/dictionary/broadband>
IPA: /'brɔːdˌbænd/
Phonetic Spelling: brawd·band
7. Stimulus
Pronunciation link: <https://www.merriam-webster.com/dictionary/stimulus>
IPA: /'stim.jə.ləs/
Phonetic Spelling: stim·yuh·luhs
8. Equivalent
Pronunciation link: <https://www.merriam-webster.com/dictionary/equivalent>
IPA: /ɪ'kwɪv.ə.lənt/
Phonetic Spelling: ih·kwiv·uh·luhnt
9. Decibels
Pronunciation link: <https://www.merriam-webster.com/dictionary/decibel>
IPA: /'des.əˌbəl/
Phonetic Spelling: des·uh·bel
10. Tripod
Pronunciation link: <https://www.merriam-webster.com/dictionary/tripod>
IPA: /'traɪ.pɑːd/
Phonetic Spelling: try·pod
11. Tactile
Pronunciation link: <https://www.merriam-webster.com/dictionary/tactile>

- IPA: /'tæk.taɪl/ , /'tæk.təl/
Phonetic Spelling: tak·tyle, tak·tuhl
12. Occipital
Pronunciation link: <https://www.merriam-webster.com/dictionary/occipital>
IPA: /ɑ:k'sɪp.ə.təl/
Phonetic Spelling: ahk·sip·uh·tuhl
13. Protuberance
Pronunciation link: <https://www.merriam-webster.com/dictionary/protuberance>
IPA: /proʊ'tu:.bə.əns/
Phonetic Spelling: proh·too·buh·ruhns
14. Graphical
Pronunciation link: <https://www.merriam-webster.com/dictionary/graphical>
IPA: /'græf.ɪ.kəl/
Phonetic Spelling: graf·ih·kuhl
15. Cochlear
Pronunciation link: <https://www.merriam-webster.com/dictionary/cochlear>
IPA: /'kɑ:k.li.ə/
Phonetic Spelling: kaak·lee·er
16. Familiarization
Pronunciation link: <https://www.merriam-webster.com/dictionary/familiarization>
IPA: /fə'mɪl.jə.ə'zeɪ.ʃən/
Phonetic Spelling: fuh·mil·yuh·ruh·zay·shuhn
17. Auditory
Pronunciation link: <https://www.merriam-webster.com/dictionary/auditory>
IPA: /'ɔ:.də.tə:r.i/
Phonetic Spelling: aw·duh·tor·ee
18. Orientation
Pronunciation link: <https://www.merriam-webster.com/dictionary/orientation>
IPA: /,ɔ:r.i.ən'teɪ.ʃən/
Phonetic Spelling: or·ee·uhn·tay·shuhn
19. Predefined
Pronunciation link: <https://www.merriam-webster.com/dictionary/predefined>
IPA: /,pri:.di'faɪnd/
Phonetic Spelling: pree·duh·fynd
20. Localization
Pronunciation link: <https://www.merriam-webster.com/dictionary/localization>
IPA: /,ləʊ.kə.lə'zeɪ.ʃən/
Phonetic Spelling: loh·kuh·luh·zay·shuhn
21. Metrics
Pronunciation link: <https://www.merriam-webster.com/dictionary/metric>
IPA: /'mɛt.rɪk/
Phonetic Spelling: met·rik
22. Diagonal
Pronunciation link: <https://www.merriam-webster.com/dictionary/diagonal>

IPA: /dar'æg.ənəl/

Phonetic Spelling: dye·ag·uh·nuhl

23. Azimuths

Pronunciation link: <https://www.merriam-webster.com/dictionary/azimuth>

IPA: /'æz.ə.məθ/

Phonetic Spelling: az·uh·muth

24. Classification

Pronunciation link: <https://www.merriam-webster.com/dictionary/classification>

IPA: /,klæs.ə.fi'keɪ.fən/

Phonetic Spelling: klas·uh·fih·kay·shuhn

25. Impairment

Pronunciation link: <https://www.merriam-webster.com/dictionary/impairment>

IPA: /ɪm'per.mənt/

Phonetic Spelling: im·pair·muhnt