Naval Submarine Medical Research Laboratory

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Naval Submarine Medical Research Laboratory (NSMRL) Facility Certification for Method 1 of ASA/ANSI S3.71-2019, "Methods for Measuring the Effect of Head-worn Devices on Directional Sound Localization in the Horizontal Plane"

by:

Derek W. Schwaller
Stephanie J. Karch
Jeremy S. Federman

Approved and Released by:
M. H. Jamerson, CAPT, MSC, USN
Commanding Officer
NAVSUBMEDRSCHLAB

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Derek Schwaller
Stephanie Karch
Jeremy Federman

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14. ABSTRACT

The Naval Submarine Medical Research Laboratory (NSMRL) created a test facility in accordance with Method 1 of the Acoustical Society of America (ASA) and the American National Standards Institute (ANSI) standard S3.71-2019 “Methods for Measuring the Effect of Head-worn Devices on Directional Sound Localization in the Horizontal Plane.” This technical report describes the open-ear (baseline) performance used to certify the test facility designed and used at the NSMRL.

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Approved and Released by:

JAMERSON.MATTHEW.HUNTER.1269308288 Digitally signed by JAMERSON.MATTHEW.HUNTER.1269308288 Date: 2023.05.31 08:34:03 -04'00'

M. H. Jamerson, CAPT, MSC, USN
Commanding Officer
Naval Submarine Medical Research Laboratory
Submarine Base New London Box 900
Groton, CT 06349-5900

Administrative Information:

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Executive Summary

The Naval Submarine Medical Research Laboratory (NSMRL) created a test facility in accordance with Method 1 of the Acoustical Society of America (ASA) and the American National Standards Institute (ANSI) standard S3.71-2019 “Methods for Measuring the Effect of Head-worn Devices on Directional Sound Localization in the Horizontal Plane” (except where noted in “Procedures”). This technical report describes the open-ear (baseline) performance used to certify the test facility designed and used at NSMRL. The test space was a typical office space that utilized equipment designed to meet the specifications described in Method 1 from the ASA/ANSI standard S3.71-2019. Facility performance was measured with a total of 23 subjects in an open-ear condition. The results showed a mean score of 94.9% correct for the facility performance in the open-ear (baseline) condition for Method 1. Per ASA/ANSI S3.71-2019, for a facility such as the one described herein to be certified for use to measure and test any hearing protection device under the standard, the mean open-ear (baseline) performance must be greater than 90% correct. The results from this effort indicate that the test facility is qualified for use when measuring the effect of head-worn devices on horizontal localization.

Author Note: Correspondence should be addressed to Jeremy S. Federman, PhD, Naval Submarine Medical Research Laboratory, Submarine Base New London, Groton, CT 06349-5900, email: jeremy.s.federman.civ@health.mil.

1. Introduction

The Acoustical Society of America (ASA) and American National Standards Institute (ANSI) published a new standard in 2019 that provides scientists and researchers with a standardized procedure to follow when investigating the effect hearing protection devices (HPDs) and other head-worn devices (e.g., helmets) have on the ability to localize to sound originating in the horizontal sound field. This standard, S3.71-2019 "Methods for Measuring the Effect of Head-worn Devices on Directional Sound Localization in the Horizontal Plane" (hereafter referred to as 'the standard') is comprised of three methods that vary in purpose and facility requirements. The first method, Method 1, is designed to be easiest to implement, requires the least amount of time for testing, and can take place either indoors or outdoors. Method 1 is an auditory search task, with eight loudspeakers and eight possible responses, accomplished in 192 trials. The main metric of performance is total percent accuracy in identifying the correct loudspeaker and is the focus of the current report. Method 1, which is considered a device screening tool, requires approximately 25 minutes test time per participant to complete.

The Naval Submarine Medical Research Laboratory (NSMRL) Regional Hearing Conservation Program of Record has built a hearing protection device (HPD) test and evaluation facility. The facility is capable of testing hearing protection and head-worn devices in accordance with the most current versions of ASA/ANSI standards S3.2, S3.7, S3.19 – 1974, S12.42, S12.6, S12.68, and S12.71. NSMRL is expanding its test and evaluation capabilities to include testing in accordance with the three Methods outlined in ASA/ANSI S3.71-2019. As this is a new standard, there are no publicly available data that were measured in accordance with the three Methods outlined in the standard. Additionally, the output metrics from the three Methods have not been compared to each other. NSMRL, along with the Air Force Research Laboratory and the United States Army Aeromedical Research Laboratory, are investigating the consistency of the results in order to validate the standard. Results from this tri-service effort will be available in a forthcoming manuscript.

Regarding Method 1, NSMRL created a facility in accordance with the design and technical specifications of the standard. Method 1 from the standard is designed to quickly measure the effect of any head-worn device on directional sound localization in the horizontal plane, with a coarser resolution of degrees between loudspeakers than that of Method 2. In accordance with the standard, the baseline, (i.e., open-ear) performance of the facility must be measured and satisfy two stipulations. First, the percent correct group mean in the open-ear condition (using 20 subjects who have not previously demonstrated the ability to perform the localization task) is to meet or exceed 70% correct while following all procedures described for Method 1 (section 7.1), hereafter referred to as 'stipulation 1.' Second, the group mean using data from 20 subjects who meet inclusion criteria for performance (section 4.1.6.2) must meet or exceed 90% correct while following all procedures described for Method 1 (section 7.2), hereafter referred to as 'stipulation 2.' The aim of the current effort was to certify a test space at NSMRL for testing

Method 1 of the standard with slight deviation applicable to methods 2 and 3, and to demonstrate that both stipulations 1 and 2 required for such testing were satisfied.

2. Background of Methodology

For detailed descriptions of each of the requirements in the standard, the interested reader can refer to the full text in ASA/ANSI S3.71-2019. Exact sections of each requirement followed in this report can be viewed in Table 1.

Table 1. List of ASA/ANSI S3.71-2019 Requirements Followed.

Requirements	Section
Screening physical characteristics	4.1.1
Head, pinnae, and ear canal inspection	4.1.2
Physical measures of the head	4.1.3
Gender[1]	4.1.4
Visual acuity	4.1.5
Unaided air-conduction hearing thresholds	4.1.6.1
Minimum localization performance	4.1.6.2
Sound field generation by each loudspeaker	6.1
Stimulus spectrum characteristics	6.1.1
Stimulus duration	6.1.2
Loudspeakers utilized	6.2
Test space size	7.2.2.1
Loudspeaker positions Deviation: Opted to follow this requirement (not required for Method 1).	7.2.2.2
Loudspeaker construction, position, label Deviation: Omitted use of ‘G’ to avoid visual confusion with ‘C’. Instead used letters ‘A’, ‘B’, ‘C’, ‘D’, ‘E’, ‘F’, ‘H’, and ‘I’	7.3.1
Adjustable chair location	7.3.3
Test stimulus presentation	8.2
Use of chin rest and Subject head position during testing	8.3
Generation, presentation and measurement of background noise	8.6.1
Test paradigm	8.6.2
Data analysis	8.6.3

[1] “Gender” is not recommended by the American Psychological Association as equivalent to “sex,” but was the word used by ASA/ANSI, and is inferred to refer to the two most common biological sex assignments at birth, rather than any other meaning.

3. Methods

3.1 Institutional Review Board (IRB) Approval

All reported research was conducted under the purview of the Institutional Review Board at NSMRL (Department of Defense IRB Assurance number: DoD N-40035) under protocol number NSMRL.2021.0003.

3.2 Subjects

A total of 25 adults provided verbal consent to participate in the current effort. Twenty-three subjects, aged 18 to 50 years (mean of 34 ± SD of 10), met inclusion criteria and completed a seven-item ANSI-designed survey and data collection. Each subject was found to have binaural hearing sensitivity equal to or less than 20 dB HL at octave band frequencies 125 to 8,000 Hz (see 4.1.6.1 in the standard); ear canals clear of excessive cerumen and/or foreign debris, able to use insert earplugs (see 4.1.2 in the standard); and visual acuity better than 20/30 as measured with a Snellen test (see 4.1.5 in the standard). The gender ratio of the 23 subjects who completed data collection was 52% female (n = 12) to 48% male (n = 11) and was within limits stipulated in the standard (see 4.1.4 in the standard). The data for these 23 subjects are included in the analysis for stipulation 1.

Two of the 23 subjects did not meet the inclusion criteria for performance in the standard (section 4.1.6.2). Although those subjects scored between 70% and 90% correct during the testing of stipulation 1, per section 7.1 Note 2 of the standard, the data from a subject with this level of performance can be used to certify the facility, but not in the performance measure of devices. One of the remaining 21 subjects was excluded at the principal investigator's discretion. They were excluded from statistical analyses due to an anomaly with study test stimuli. The data from twenty subjects, aged 18 to 50 years (mean of 33 ± SD of 10), with a gender balance of 55% female (n = 11) to 45% male (n = 9), were included in the analysis for stipulation 2.

All subjects were compensated for their time.

3.3 Experimental Staff

The testing was conducted by the NSMRL Regional Hearing Conservation team. The experimenters were Dr. Alexa Kolias, Mr. Jake See, Mr. Derek Schwaller, Dr. Meredith McGhee, Dr. Stephanie Karch, Mr. Joshua Ginsberg, and Dr. Jeremy Federman.

3.4 Dates of Data Collection:

Data were collected between January and May 2022.

3.5 Sound Field Requirements

The sound field was measured in accordance with section 6.1 of the standard. The stimuli were generated in accordance with sections 6.1.1, 6.1.2, and 6.1.3 of the standard. These requirements were verified at the beginning of each day of data collection.

The loudspeakers used were in accordance with section 6.2 of the standard.

3.6 Facility

3.6.1 Test Room:

The test facility was established in an indoor office space at NSMRL. A scale drawing of the space is presented in Figure 1. A photo of the test space is presented in Figure 2. In accordance with section 7.2.2.1 of the standard, the test room was 6.35 m long by 4.32 m wide and 2.69 m high.

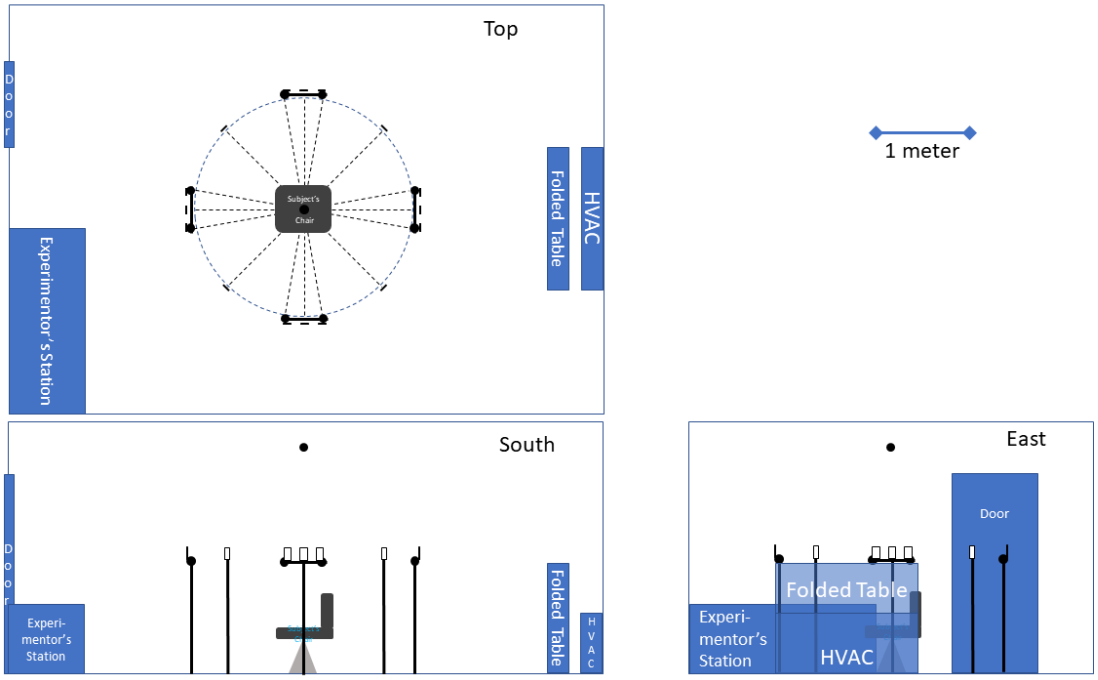

Figure 1. Scale Drawing of the Test Space. This figure shows the room as viewed from above and from perpendicular sides. In the 'Top' drawing, the dashed circle represents the perimeter of the loudspeaker array with each 45° orientation marker increment around the circle and the angles of the loudspeaker locations marked with dashed lines. The black circles represent the loudspeakers (eight in the horizontal circular array and one above the subject). In the South and East drawings (viewed from the South and East respectively), each white rectangle represents a placard (eight labeling the loudspeakers and eight labeling the orientation points). The ninth loudspeaker (black circle floating above the subject's chair) is attached to a custom-made carbon fiber structure.

Figure 2. Photo of Test Facility (Subject Station). This picture shows the test space as viewed from the entrance of the room (from the doorway on the West wall). (Photo credit: NSMRL)

3.6.2 Loudspeaker Spacing:

In accordance with section 7.3.1 of the standard, the front of each pair of loudspeakers was 1.17 m from the center of the head cylinder and spaced 40.8 cm apart, such that they were 20º apart from the perspective of the position of the listener. The loudspeaker pairs were aligned so that the centers of the pairs were separated by 90º. A ninth loudspeaker placed above the subject's chair was 2.43 m above the floor, facing down. As shown in Figure 3, each loudspeaker was marked with a number between 1 and 8. There were also eight orientation points marked by placards with the letters 'A' through 'I' (skipping 'G' to avoid confusion with 'C'). The placards were 7.75 cm wide and 13.25 cm tall, with 3.75 cm tall black Arial font. The vertical visual angle (in arc-minutes) was calculated using the four-digit approximation formula of visual angle:

Equation 1. $$Visual\ Angle = 3438 \times \frac{object\ height}{object\ distance}$$

The object height and object distance must be in the same units (Howett, 1983). Using an object height of 3.75 cm and an object distance of 117 cm results in 110 arc-minutes, which is greater than the minimum visual angle of 20/30 vision (7.5 arc-minutes, or 0.125º) (Howett, 1983). This ensured that, from the subject's chair, the placard writing would be visible and legible by the subject.

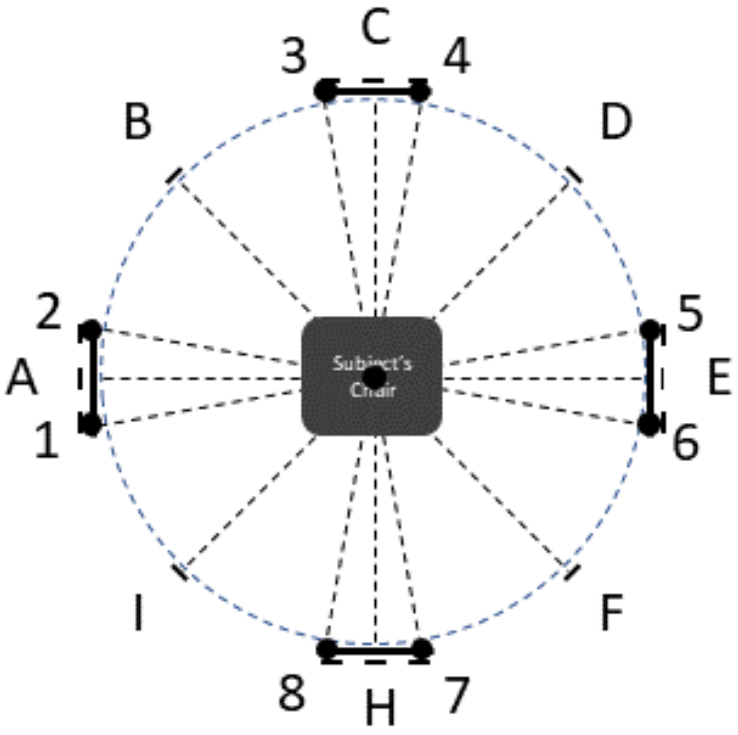

Figure 3. Loudspeaker Array. This to-scale top-down drawing shows the locations of the eight loudspeakers in the array and the ninth loudspeaker in the center of the array (above the subject's chair). The numbers and letters around the array show what was on the placards, facing the

center of the array. When the subject is facing orientation marker ‘A,’ the ‘A’ marker is considered to be at 0º, loudspeaker ‘1’ is at 350º, loudspeaker ‘2’ is at 10º, and orientation point ‘B’ is at 45º. Each orientation point is 45º from the previous one, and the center of each loudspeaker pair is 90º from the previous center of loudspeakers pairs.

3.6.3 Subject Chair:

The subject’s chair was in accordance with section 7.3.3 of the standard regarding loudspeaker height. A removable square wooden frame was placed on the floor around subject’s chair if the subject could not comfortably touch the floor with their feet. A chinrest was attached to the right armrest to ensure that the subject’s head was at the center of the loudspeaker array during testing. The subject’s chair and chinrest were in accordance with section 8.3 of the standard, which required maintaining the subject head location inside the head cylinder.

3.6.4 Instrumentation:

Otoscopic inspection of subjects’ ears was completed using a diagnostic otoscope (Welch-Allyn® 25020). Physical measures of the subjects required by the standard were made with an ear gauge (3M™ Eargage, Ear Measure 85099-00000) and head calipers (Baseline®, 12-1230). Acquisition of subjects’ hearing thresholds was completed in a double walled sound booth (Industrial Acoustics Company Inc.®; 109906) using a calibrated, FDA approved clinical audiometer (GSI 61; Grason-Stadler®, 1761, S/N: GS0096707).

Localization performance testing was completed in a converted conference room (as presented in Figures 1 and 2). Digital stimuli were generated with a computer (New Tech Solutions Inc., S/N: D17036104IW001) operating with Windows® 10 Pro (Microsoft®, Version# 1607) running LabVIEW 2019 (National Instruments Corp.®, Version #19.0) and MATLAB® 2019a (Mathworks®, Version# 9.6.0.1072779). The computer, using MADI mixer software (RME Audio®, TotalMix FX, Version# 1.40), output the digital stimuli to a MADI interface (RME Audio®, MADIFace XT USB, S/N: 23971320). The signal was then routed to a MADI digital-to-analog interface (RME Audio®, M32-DA, S/N: 23815529). The analog signal from the interface was sent to an audio amplifier (Crown Audio®, CT8150, S/N: 11000950061) and then to the loudspeakers (ORB Audio©, Mod1X). The loudspeakers were mounted on customized loudspeaker stands (AirTurn™, goSTAND) with carbon fiber tubes and connectors (DragonPlate™ Carbon Fiber).

To ensure stimuli were presented at the required sound levels in accordance with section 8.3 of the standard, the sound field was measured using a sound level meter (Bruel & Kjaer®, Type 2270, S/N: 3306957). The sound level meter used a microphone (Bruel & Kjaer®, Type 4192, S/N: 2854718) and a microphone preamplifier (Bruel & Kjaer®, Type ZC 0032, S/N:31714).

The sound level meter was calibrated with a pistonphone (Bruel & Kjaer®, Type 4230, S/N: 1206028) prior to each day of measurement.

The subject chair was used without its footrest (Collins®, 8060S S/N: 174531). The subject chin rest (Veatch Ophthalmic Instruments®, SLRI01-001) was modified to mount to the subject chair's right armrest. Subjects were visually monitored using a PTZ Camera (Sony®, SRG-120DU, S/N: 3202282).

The placards used for loudspeaker identification were custom made from white acrylic backs, 3/16" thick, with black acrylic letters, 1/8" thick. The placards were mounted on microphone stands (AirTurn™, goSTAND).

Data were processed using signal and data processing software (Matlab® 2019a; Mathworks®, Version# 9.6.0.1072779) and Excel® 2016 32-bit (Microsoft®, Version# 16.0.5356.1000).

3.7 Stimuli

In accordance with section 6.1.1 of the standard, randomly generated pink noise samples were used as the stimuli. Specifically, the noise was pink over the frequency range from 200 Hz to 14 kHz within ± 3 dB of the level at 1 kHz. In accordance with section 6.1.2 of the standard, short-duration stimuli were a total of 250 ms in duration with 10 ms linear ramps at the beginning and end of the stimulus. Conversely, long-duration stimuli were repetitions of the short-duration stimuli with a 50% duty cycle; specifically, on for 250 ms then off for 250 ms until the subject responded or for a total duration of 7 seconds, whichever was shorter. The stimuli were randomly presented in accordance with section 8.2 of the standard at 65, 70, or 75 dBA for a given trial. Background masking noise with an overall level of 50 dBA was generated from a loudspeaker located directly above the subject in accordance with section 8.6.1 of the standard.

3.8 Procedure

In order to minimize the timeframe of testing for facility certification, testing for the satisfaction of stipulation 2 was completed concurrently with the testing for the satisfaction of stipulation 1. Specifically, subjects were screened for inclusion in the testing for satisfaction of stipulation 1. Then their unoccluded localization performance was measured. If they met the inclusion criteria for performance in the standard (section 4.1.6.2), their data were used for assessing satisfaction of stipulation 2. This process is not in compliance with the standard.

The auditory localization task was conducted in accordance with section 8.6.2 of the standard. The subject responses were given verbally and then manually entered into a computer by the experimenter. The experimenter instructed the subject when to change the orientation point and when the session ended. In addition to the standard's requirements, scripted instructions were used to instruct every subject consistently (See Appendix A).

3.8 Analysis Plan

In accordance with section 8.6.3 of the standard, the data to test the satisfaction of stipulation 1 and the data to test the satisfaction of stipulation 2 were analyzed for:

1) Proportion of front-back (F/B) reversals;

2) Proportion of correct loudspeaker location identifications ('fine resolution' or 'fine correct' in the following Tables) both with and without correction for front-back reversals and with and without corrections for guessing (as per section 8.6.3 of the standard); and

3) Proportion of correct location identifications ('coarse resolution', where the subject only needs to correctly identify one of the two loudspeaker location in a loudspeaker location pair to be scored as correct) both with and without correction for front-back reversals and with and without corrections for guessing.

As defined in the standard, 'fine resolution' means the subject correctly identified the loudspeaker from which the target was presented. 'Coarse resolution' means the subject identified either of the loudspeakers from the loudspeaker pair from which the target was presented. For example, if loudspeaker 3 presented the target, the subject could respond either "3" or "4" to be correct under 'coarse resolution' scoring. The response data were analyzed for percent correct using both definitions ('fine resolution' and 'coarse resolution'). In addition to the standard's requirements, each loudspeaker orientation was analyzed separately in order to determine whether results specified in sections 7.1 and 7.2 of the standard were satisfied. Each loudspeaker location was also analyzed separately in order to examine if there were asymmetric characteristics of the facility. The data from the questionnaires, room acoustics measures, and anthropomorphic measures were reported, but were not statistically analyzed.

4. Results

4.1 Room Acoustics:

The reverberation time-60dB down (RT60) at the center of the head cylinder was calculated by measuring the reverberation time-20dB down (T20) of the center of the head cylinder and multiplying by three. The result was RT60 as estimated by T(20) (RT60(T20)) = 1.19 seconds. The levels and timing relative to the direct sound of the three maximum reflections were -7.56 dB at 6.5 ms, -12.96 dB at 14.1 ms, and -12.81 dB at 19.1 ms. It is hypothesized that those reflections were due to the floor, side walls, and end walls, respectively. There was also a reflection from the ceiling at -13.32 dB at 8.3 ms. The room noise floor was 30.7 dBA. This noise floor was primarily due to the HVAC system in the adjacent room and intermittent sounds coming from the drop ceiling that moved in response to the airflow from the HVAC system. Although there is no requirement for Method 1, for Methods 2 &3, the standard requires that each of the seven octave bands between 125 Hz and 8000 Hz be less than 35 dB SPL. The test space met that requirement every day of testing.

4.2 Subject Information:

Appendix B presents the tabulated results from each subject's anthropomorphic measures, hearing screening results, and questionnaire responses.

4.3 Facility Performance:

Percent correct calculated means and standard deviations (SDs) for open-ear (n = 23) are shown in Table 2 for all stimulus durations (Overall – All Stimuli), for short stimulus duration (Short Stimuli), and for long stimulus duration (Long Stimuli) for stipulation 1 in NSMRL's Method 1 test space.

Table 2. Group Mean and SD for Stipulation 1 Facility Performance.

Overall – All Stimuli	**Mean**	**SD**
Fine Correct	96.2%	3.6%
Fine Correct - Corrected for Guessing	95.6%	4.1%
Fine Correct - Corrected for F/B Reversals	96.2%	3.5%
Fine Correct - Corrected for Guessing and F/B Reversals	95.2%	4.5%
Proportion of F/B Reversals	0.4%	0.9%
Coarse Correct	99.5%	0.9%
Coarse Correct - Corrected for Guessing	99.3%	1.2%
Coarse Correct - Corrected for F/B Reversals	99.8%	0.5%
Coarse Correct - Corrected for Guessing and F/B Reversals	99.6%	0.8%
Short Stimuli	**Mean**	**SD**
Fine Correct	95.0%	4.8%
Fine Correct - Corrected for Guessing	94.3%	5.5%
Fine Correct - Corrected for F/B Reversals	95.2%	4.7%
Fine Correct - Corrected for Guessing and F/B Reversals	93.8%	6.0%
Proportion of F/B Reversals	0.5%	1.2%
Coarse Correct	99.4%	1.2%
Coarse Correct - Corrected for Guessing	99.2%	1.6%
Coarse Correct - Corrected for F/B Reversals	99.7%	0.5%
Coarse Correct - Corrected for Guessing and F/B Reversals	99.5%	0.9%
Long Stimuli	**Mean**	**SD**
Fine Correct	99.5%	1.3%
Fine Correct - Corrected for Guessing	99.4%	1.5%
Fine Correct - Corrected for F/B Reversals	99.5%	1.3%
Fine Correct - Corrected for Guessing and F/B Reversals	99.3%	1.7%
Proportion of F/B Reversals	0.1%	0.6%
Coarse Correct	99.7%	1.0%

Coarse Correct - Corrected for Guessing	99.6%	1.3%
Coarse Correct - Corrected for F/B Reversals	99.8%	0.9%
Coarse Correct - Corrected for Guessing and F/B Reversals	99.7%	1.5%

Note. As described in section 8.6.3 of the standard, the data presented are the front-back (F/B) reversals, fine percent correct, coarse percent correct, and the percent correct data with and without corrections for F/B reversals and guessing.

The percent correct calculated means and SDs for open-ear (n = 20) are shown in Table 3 for all stimulus durations (Overall – All Stimuli), short stimulus duration (Short Stimuli), and for long stimulus duration (Long Stimuli) for stipulation 2 in the NSMRL Method 1 test space.

Table 3. Group Mean and SD for Stipulation 2 Facility Performance.

Overall - All Stimuli	**Mean**	**SD**
Fine Correct	96.8%	2.3%
Fine Correct - Corrected for Guessing	96.3%	2.6%
Fine Correct - Corrected for F/B Reversals	96.8%	2.3%
Fine Correct - Corrected for Guessing and F/B Reversals	96.0%	3.0%
Proportion of F/B Reversals	0.2%	0.4%
Coarse Correct	99.6%	0.5%
Coarse Correct - Corrected for Guessing	99.4%	0.7%
Coarse Correct - Corrected for F/B Reversals	99.8%	0.5%
Coarse Correct - Corrected for Guessing and F/B Reversals	99.6%	0.8%
Short Stimuli	**Mean**	**SD**
Fine Correct	95.9%	3.0%
Fine Correct - Corrected for Guessing	95.3%	3.4%
Fine Correct - Corrected for F/B Reversals	96.0%	3.0%
Fine Correct - Corrected for Guessing and F/B Reversals	94.9%	3.8%
Proportion of F/B Reversals	0.3%	0.6%
Coarse Correct	99.5%	0.6%
Coarse Correct - Corrected for Guessing	99.4%	0.8%
Coarse Correct - Corrected for F/B Reversals	99.8%	0.5%
Coarse Correct - Corrected for Guessing and F/B Reversals	99.6%	0.8%
Long Stimuli	**Mean**	**SD**
Fine Correct	99.4%	1.4%
Fine Correct - Corrected for Guessing	99.3%	1.6%
Fine Correct - Corrected for F/B Reversals	99.4%	1.4%
Fine Correct - Corrected for Guessing and F/B Reversals	99.2%	1.8%
Proportion of F/B Reversals	0.1%	0.6%
Coarse Correct	99.7%	1.0%
Coarse Correct - Corrected for Guessing	99.6%	1.4%
Coarse Correct - Corrected for F/B Reversals	99.8%	0.9%
Coarse Correct - Corrected for Guessing and F/B Reversals	99.6%	1.7%

Note. As described in section 8.6.3 of the standard, data included the F/B reversals, fine percent correct, coarse percent correct, and the percent correct data with and without corrections for F/B reversals and guessing.

Facility performance analyzed for each orientation is reported in Appendix C.

Facility performance analyzed for each loudspeaker location is reported in Appendix D.

4.4 Uncertainty Analysis:

The standard and expanded uncertainty for the total measurement, including all the individual contributing parameters and their measured or estimated uncertainty values, are shown in Table 4.

Table 4. Uncertainty metrics.

Quantity	Estimate %	Standard uncertainty U_i %	Probability distribution	Sensitivity coefficient C_i	Uncertainty contribution $C_i U_i$ %
PFB_e	$\overline{PFBe}$	3	Normal	1	3
PC_{FR}	$\overline{PC}_{FR}$	5	Normal	1	5
PC_{CR}	$\overline{PC}_{CR}$	1	Normal	1	1
δ_{AM}	0	0.5	Normal	1	0.5
δ_{HT}	0	2	Normal	1	2
$\delta_{RESPONSE}$	0	0.2	Normal	1	0.2
$\delta_{SUBJECT}$	0	1	Normal	1	1
$\delta_{SOUND\ FIELD}$	0	0.5	Normal	1	0.5
$\delta_{DEVICE\ FIT}$	0	1	Normal	1	1

Metric	Standard (%)	Expanded (%)
PFB_e	3.9	7.9
PC_{FR}	5.6	11.2
PC_{CR}	2.7	5.5

Note. All acronyms presented in Table 4 are defined in section 9.1 of the standard. The standard and expanded uncertainty were calculated using the formulas and estimated values from section 9.1 of the standard. No better estimation for the uncertainty values were available at the time of writing this report.

5. Conclusion

All requirements of the standard for conducting baseline, open-ear condition testing indoors in accordance with the Method 1 procedures were satisfied, with the one deviation from the

standard procedures that both stipulations were tested concurrently. All 23 subjects who passed the initial screening (in accordance with sections 4.1.1, 4.1.2, 4.1.3, 4.1.4, 4.1.5, and 4.1.6.1) exceeded 70% performance on all performance metrics. The means of the 24 percent-correct output metrics ranged from 93.8% to 99.8%. Therefore, stipulation 1 was satisfied. Mean performance of subjects who met inclusion criteria (section 4.1.6.2) was measured at 96.8% for both short and long stimulus durations. The means of the 24 percent-correct metrics, from the subjects who met inclusion criteria for stipulation 2, ranged from 94.9% to 99.8%. All performance metrics for the room performance are greater than the required minimum value of 90% to satisfy stipulation 2. Testing both stipulations concurrently, although a deviation from the standard, might have introduced error that is not accounted for in the performance limits in sections 4.1.6.2 and stipulation 2. However, since the performance results were equal to or greater than 94.9%, it is unlikely that the introduced error would have reduced the performance measures below the required 90%. Taken together, these results indicate that the test space at NSMRL met the performance requirements to conduct Method 1 testing of head-worn devices in accordance with the standard. As a result, Method 1 testing according to the standard was permissible.

6. References

American National Standards Institute. (2019). Methods for measuring the effect of head-worn devices on directional sound localization in the horizontal plane (ANSI/ASA S3.71-2019). In. New York: American National Standards Institute.

Howett, Gerald L. (1983). Size of Letters Required for Visibility as a Function of Viewing Distance and Observer Visual Acuity. National Bureau of Standards Technical Note #1180.

7. Appendices

APPENDIX A: Subject Instructions

“Please face the sign that reads [INSERT THE SUBJECT’S STARTING PLACARD HERE]. This is your starting placard. You will be asked to place your chin on the chin rest and keep it there throughout the entire test session. In a few minutes, a sound will play from one of the speakers that surround you. Your job is to turn and look at the speaker where you think the sound is coming from AND then say out loud what that speaker number is. Once you have said your choice out loud, you are to turn your chair and face the starting placard. We will repeat this 24 times. You then will be told a new starting placard to face – and we will repeat the entire process another seven times. In total, this should take less than 45 minutes to complete. Let’s practice.”

APPENDIX B: Subject Information

Subject Number	1	2	3	4	5	6	7	8	9	10	11	12	13
Included in Data to Satisfy Stipulation 1	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No
Included in Data to Satisfy Stipulation 2	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	No
Anthropomorphic Metric	**Measures by Subject**												
Bitragion Width (cm)	13	13.5	14	12	14	13	12	15	14	13	15	16	16
Head Height (cm)	13	14	14	14	13	12	13	14	14	13	13	14	14
Ear Canal Size	Medium	Large	Medium	Small	Medium	Medium	Medium	Large	Large	Small	Medium	Medium	Large
Hearing Sensitivity	**Passing Measure by Subject**												
125 Hz Right Ear <=20HL	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
250 Hz Right Ear <=20HL	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
500 Hz Right Ear <=20HL	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
1000 Hz Right Ear <=20HL	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
2000 Hz Right Ear <=20HL	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
4000 Hz Right Ear <=20HL	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
8000 Hz Right Ear <=20HL	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
125 Hz Left Ear <=20HL	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
250 Hz Left Ear <=20HL	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
500 Hz Left Ear <=20HL	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
1000 Hz Left Ear <=20HL	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
2000 Hz Left Ear <=20HL	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No
4000 Hz Left Ear <=20HL	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No
8000 Hz Left Ear <=20HL	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
ANSI Questionnaire	**Response by Subject**												
Age (years)	50	34	48	32	18	22	45	43	20	22	37	39	38
Have you ever received one-on-one personal instruction in the fitting of head-worn devices or hearing protectors?	No	No	Yes	No	No	No	No	Yes	Yes	No	Yes	Yes	Yes
Within the past two years, have you received group instruction on, or watched videotaped or computer-based instructions about, how to fit head-worn devices or hearing protectors?	No	No	Yes	Yes	No	No	No	Yes	No	No	No	No	No
Within the past two years, have you participated in an experiment involving the use of head-worn devices or hearing protection?	No	No	Yes	No	No	No	Yes	Yes	Yes	No	No	Yes	Yes
Within the past two years, on how many occasions have you worn head-worn devices or hearing protectors because you were exposed to noise as part of your occupation, military duty, or other activity?	0	50	Many	6	0	0	6	20	>300	0	40	0	12
How many times have you worn earplugs while sleeping or swimming?	0	500	Swimming, a couple times	60	0	0	0	0	0	0	0	0	0
Within the past two years, on how many occasions have you participated in an experiment involving the localization of sound sources?	0	0	1	0	0	0	6	12	0	0	0	8	8
Within the past two years, on how many occasions have you participated in an experiment involving the localization of sound sources while wearing the head-worn device being evaluated in this experiment?	0	0	1	0	0	0	0	10	0	0	0	8	8

Subject Number	14	15	16	17	18	19	20	21	22	23	24	25
Included in Data to Satisfy Stipulation 1	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes
Included in Data to Satisfy Stipulation 2	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	No	Yes	No	Yes
Anthropomorphic Metric	**Measures by Subject**											
Bitragion Width (cm)	14	14	16	15	15	16	15	14	15	14	15	15
Head Height (cm)	14	13.5	14	13	14	14	14.5	15	12	14	14	14
Ear Canal Size	large	medium	large	medium	large	x-large	medium	large	small	small	large	medium
Hearing Sensitivity	**Passing Measure by Subject**											
125 Hz Right Ear <=20HL	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
250 Hz Right Ear <=20HL	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
500 Hz Right Ear <=20HL	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
1000 Hz Right Ear <=20HL	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
2000 Hz Right Ear <=20HL	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
4000 Hz Right Ear <=20HL	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
8000 Hz Right Ear <=20HL	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes
125 Hz Left Ear <=20HL	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
250 Hz Left Ear <=20HL	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
500 Hz Left Ear <=20HL	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
1000 Hz Left Ear <=20HL	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
2000 Hz Left Ear <=20HL	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
4000 Hz Left Ear <=20HL	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
8000 Hz Left Ear <=20HL	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes
ANSI Questionnaire	**Response by Subject**											
Age (years)	29	21	28	37	37	37	33	44	43	20	54	41
Have you ever received one-on-one personal instruction in the fitting of head-worn devices or hearing protectors?	No	No	No	No	Yes	No	No	No	Yes	No	Yes	Yes
Within the past two years, have you received group instruction on, or watched videotaped or computer-based instructions about, how to fit head-worn devices or hearing protectors?	No	No	No	No	No	No	No	No	Yes	No	No	No
Within the past two years, have you participated in an experiment involving the use of head-worn devices or hearing protection?	No	No	Yes	Yes	Yes	No	No	No	Yes	No	No	Yes
Within the past two years, on how many occasions have you worn head-worn devices or hearing protectors because you were exposed to noise as part of your occupation, military duty, or other activity?	1	0	0	24	25	0	8	5	0	0	50	4-6
How many times have you worn earplugs while sleeping or swimming?	0	0	8	1	0	0	0	0	1	0	0	0
Within the past two years, on how many occasions have you participated in an experiment involving the localization of sound sources?	0	0	1	1	2	0	0	0	8	0	0	1

APPENDIX C: Independent Orientation Data

As shown in Table C1, the data from the eight orientations were analyzed separately for their percent correct, with fine resolutions, without compensation for F/B reversals.

Table C1. Total Overall Mean Correct by Orientation.

Orientation	Correct
A	96%
B	96%
C	99%
D	96%
E	96%
F	97%
H	96%
I	98%

As shown in Table C2, the data from the eight orientations were also analyzed separated into the short stimulus durations. The data presented are the mean percent correct with fine resolution, without compensation for front/back reversals, for the short stimulus duration for each orientation.

Table C2. Total Mean Correct by Orientation (Short).

Orientation	Correct
A	96%
B	95%
C	99%
D	95%
E	95%
F	96%
H	95%
I	97%

As shown in Table C3, the percent correct for the group from the eight orientations were also analyzed separated into the long stimulus durations. The data presented are the mean percent correct with fine resolution, without compensation for front/back reversals, for the long stimulus duration for each orientation.

Table C3. Total Mean Correct by Orientation (Long).

Orientation	Correct
A	100%
B	100%
C	99%
D	99%
E	100%
F	98%
H	99%
I	100%

APPENDIX D: Independent Loudspeaker Data

As shown in Figures D1 to D6, the data from the eight loudspeaker locations were processed separately for their percent correct, with fine resolution, without compensation for front/back reversals.

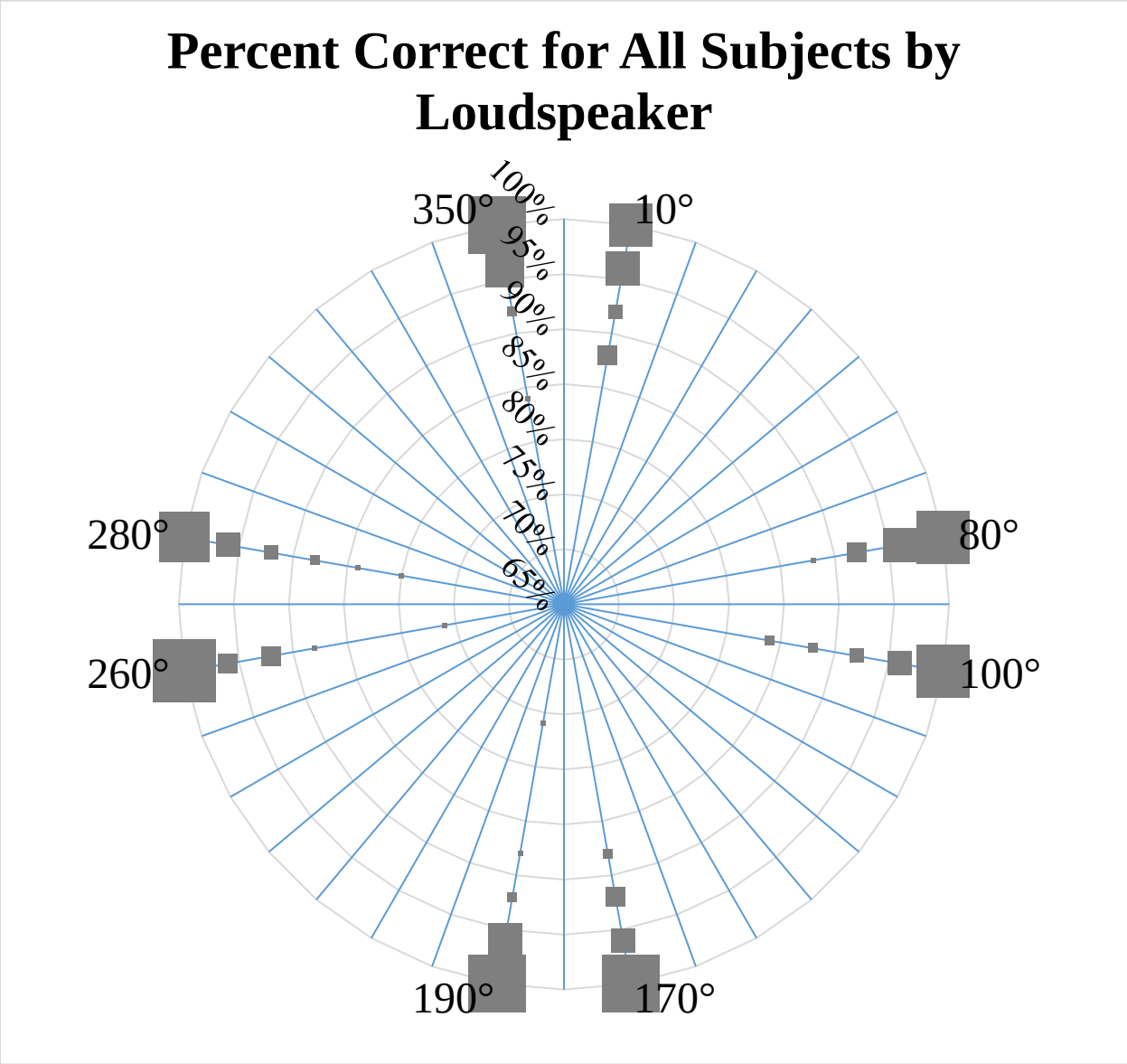

Figure D1. Percent Correct for Each Subject. Percent correct data, with fine resolution, without compensation for front/back reversals for each subject, for both short and long durations combined. The angles (in degrees (º)) are shown for the eight loudspeakers, referenced with the midpoint between loudspeakers 1 and 2 as 0º. The radius is the percent correct (60 to 100%). The squares are a subject's score. The marker size of the squares is proportional to the number of subjects who scored that value.

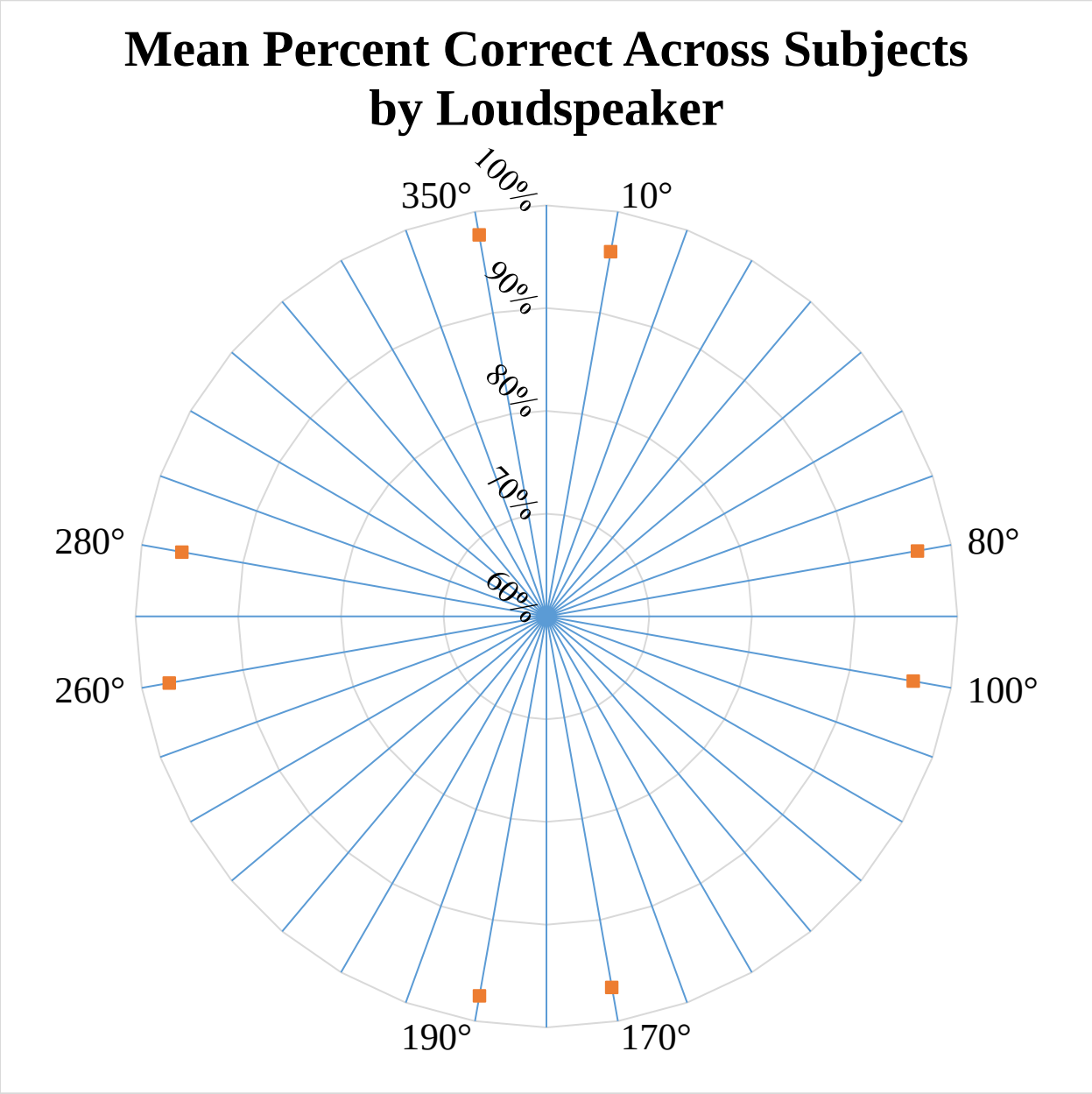

Figure D2. Mean Percent Correct Across Subjects. Mean percent correct data, with fine resolution, without compensation for front/back reversals for each loudspeaker averaged across subjects. The angles (in degrees (º)) are shown for the eight loudspeakers, referenced with the midpoint between loudspeakers 1 and 2 as 0º. The radius is the percent correct (60 to 100%). Orange squares represent mean percent correct data for each loudspeaker location.

The data from the eight loudspeaker locations were also processed separately for their percent correct, with fine resolution, without compensation for front/back reversals separately for the

long and short stimuli durations. The results are in Figures D3 and D4 for the short duration and Figures D5 and D6 for the long duration.

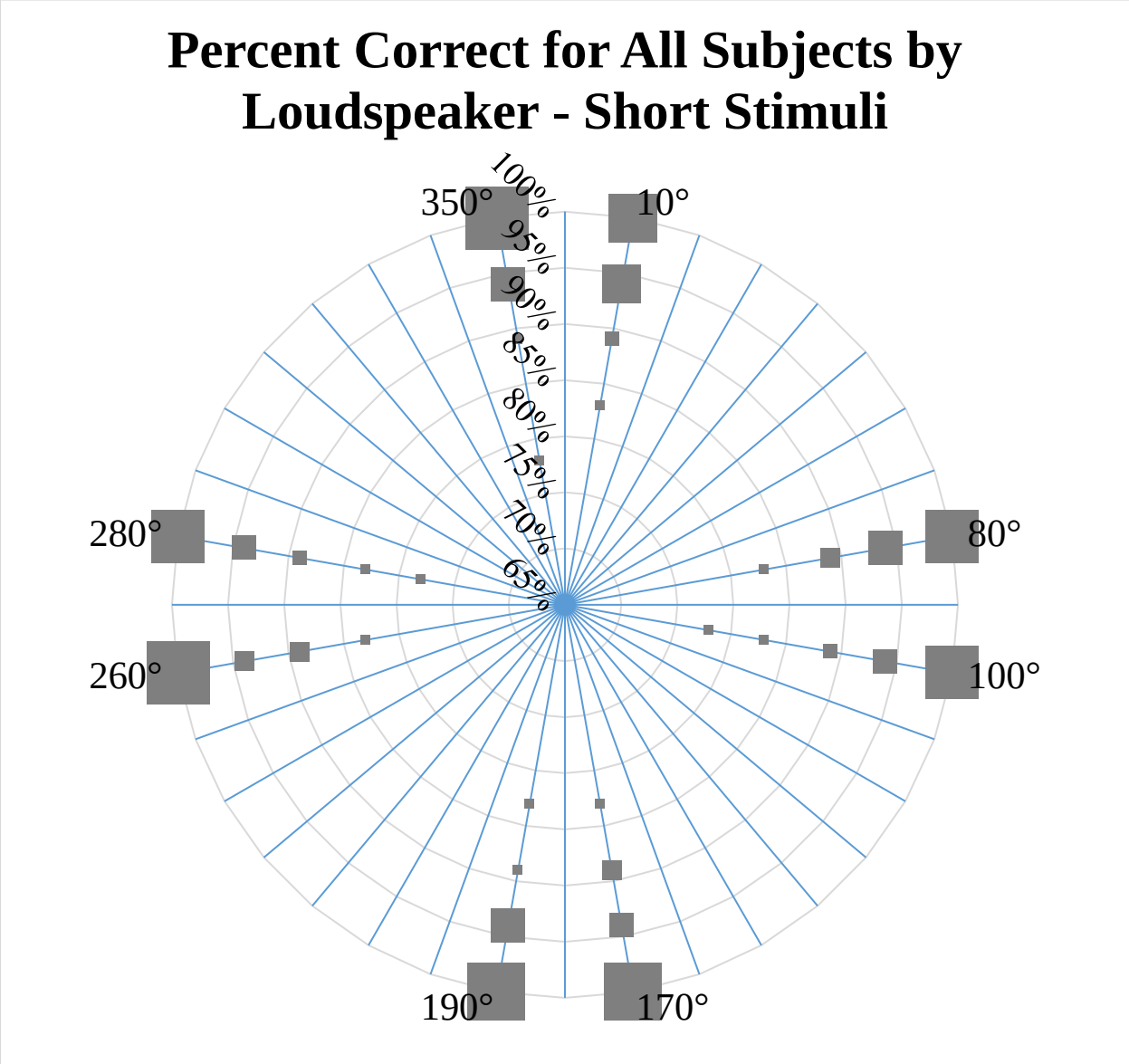

Figure D3. Percent Correct for Short Stimuli for Each Subject. Percent correct data, with fine resolution, without compensation for front/back reversals for each loudspeaker for all subjects of the short duration stimuli data. The angles (in degrees (º)) are shown for the eight loudspeakers, referenced with the midpoint between loudspeakers 1 and 2 as 0º. The radius is the percent correct (60 to 100%). The squares are a subject's score. The marker size of the squares is proportional to the number of subjects who scored that value.

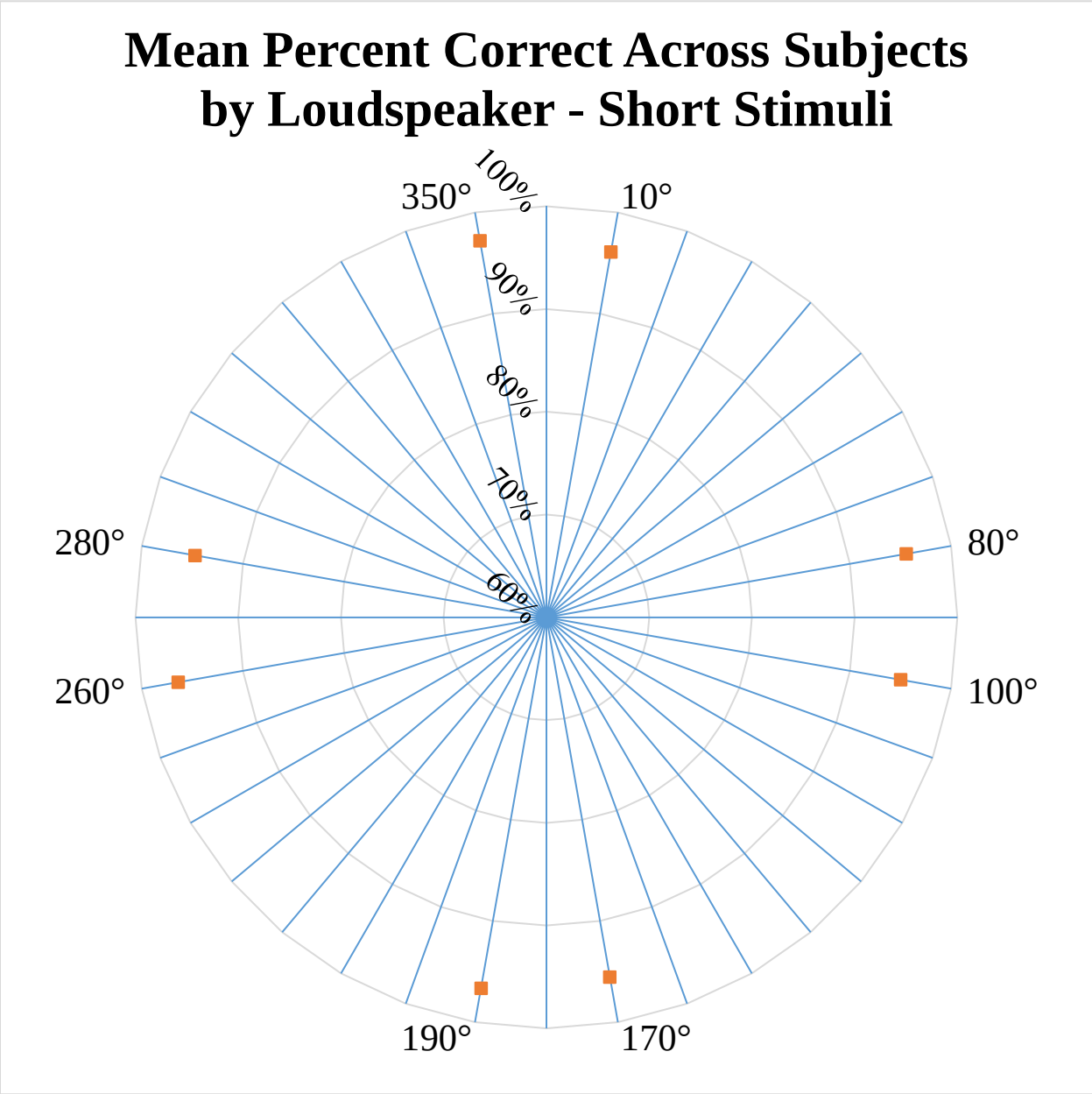

Figure D4. Mean Percent Correct for Short Stimuli Across Subjects. Mean percent correct data, with fine resolution, and without compensation for front/back reversals for each loudspeaker averaged across subjects of the short duration stimuli data. The angles (in degrees, (º)) are shown for the eight loudspeakers, referenced with the midpoint between loudspeakers 1 and 2 as 0º. The radius is the percent correct (60 to 100%). Orange squares represent mean percent correct data for each loudspeaker location.

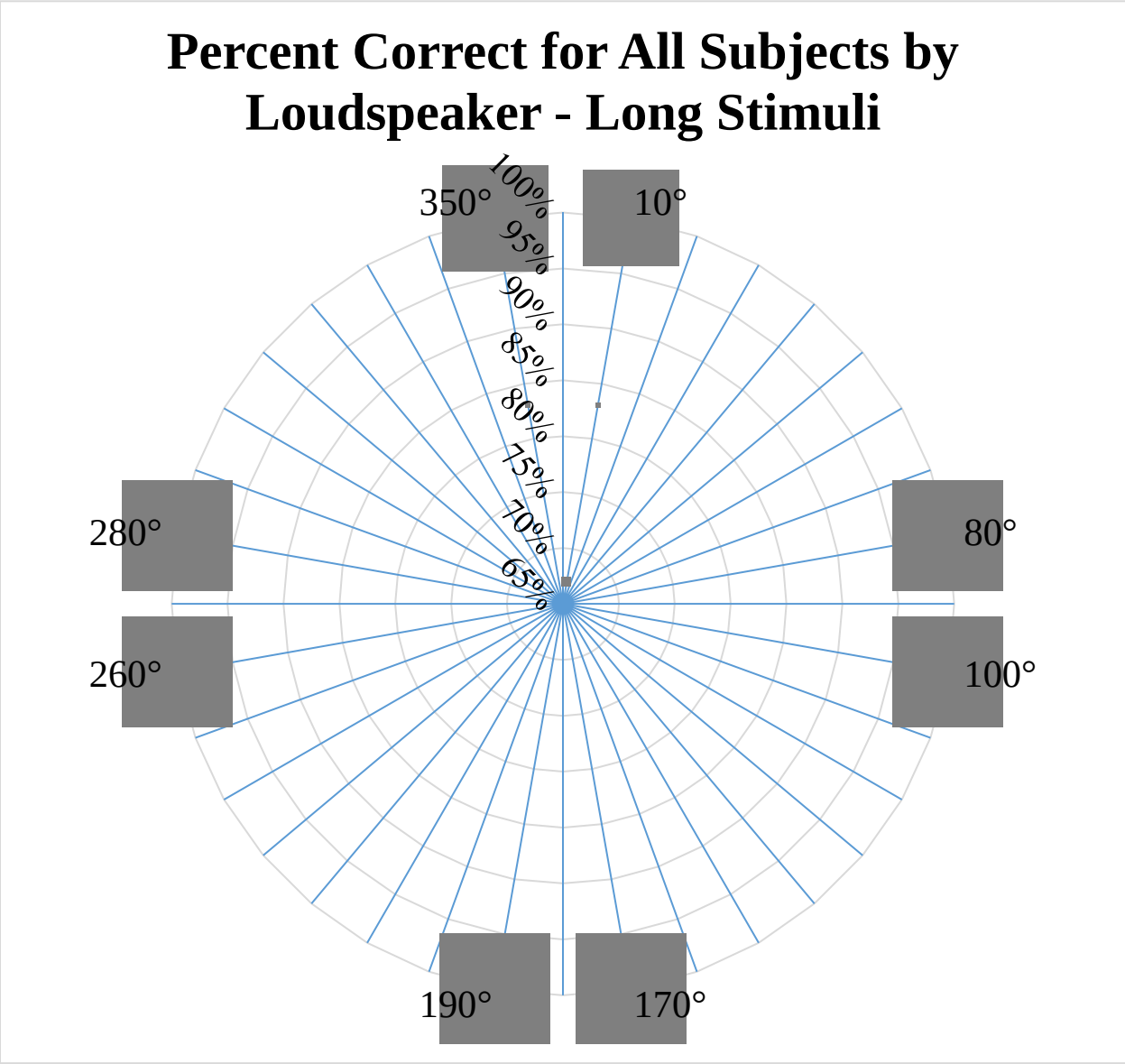

Figure D5. Percent Correct for Long Stimuli for Each Subject. Percent correct data, with fine resolution, and without compensation for front/back reversals for each loudspeaker for all subjects of the long duration stimuli data. The angles (in degrees (º)) are shown for the eight loudspeakers, referenced with the midpoint between loudspeakers 1 and 2 as 0º. The radius is the percent correct (60 to 100%). The squares are a subject's score. The marker size of the squares is proportional to the number of subjects who scored that value.

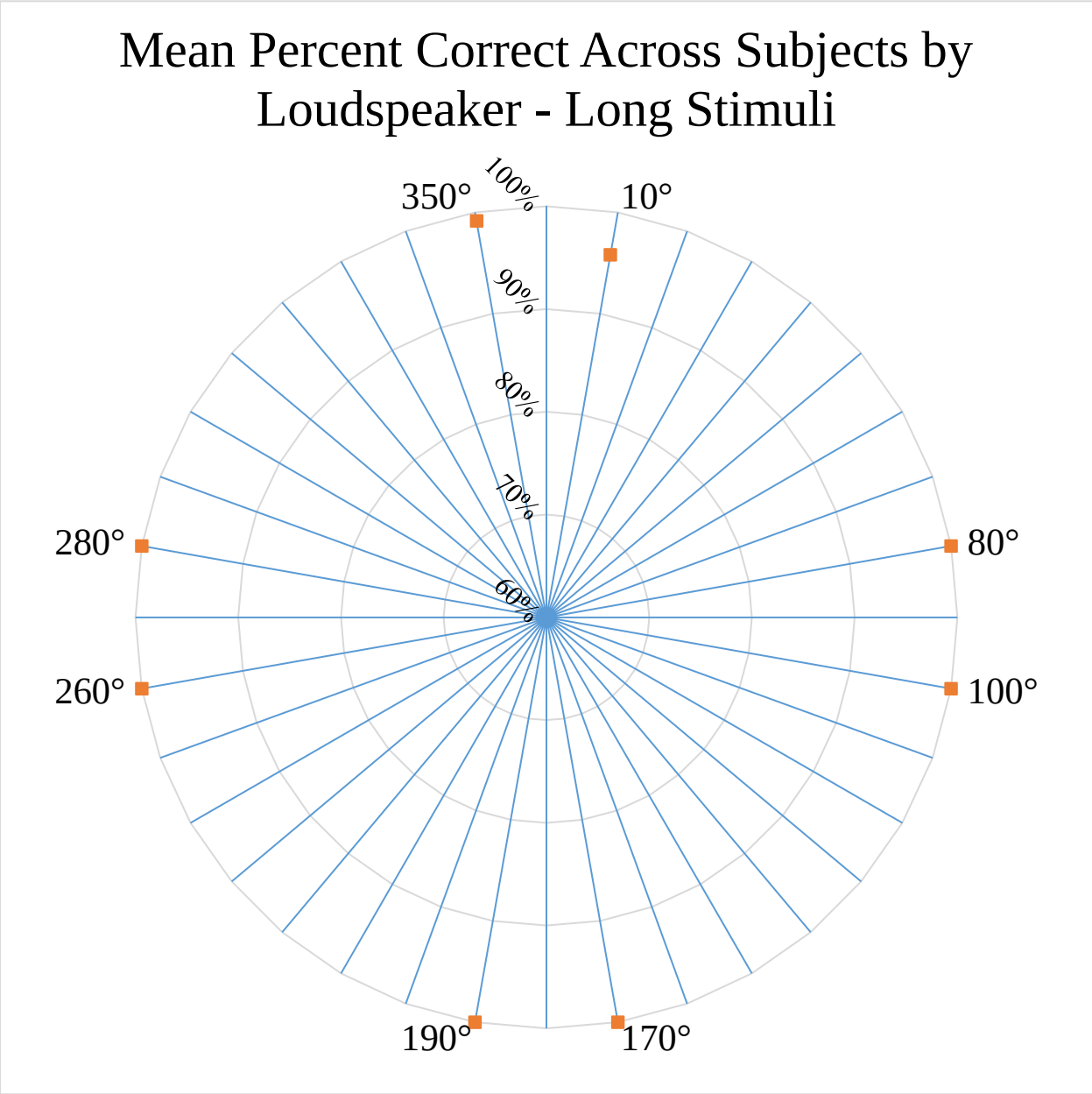

Figure D6. Mean Percent Correct for Long Stimuli Across Subjects. Mean percent correct data, with fine resolution, and without compensation for front/back reversals for each loudspeaker averaged across subjects of the long duration stimuli data. The angles (in degrees (º)) are shown for the eight loudspeakers, referenced with the midpoint between loudspeakers 1 and 2 as 0º. The radius is the percent correct (60 to 100%). Orange squares represent mean percent correct data for each loudspeaker location.