Directionality: LINK by Eargo

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Introduction

Hearing aids are the primary modality used to treat adults with hearing loss. According to the National Institute on Deafness and Other Communication Disorders (NIDCD), approximately 28.8 million adults in the United States could benefit from the use of hearing aids.[1] A common primary concern reported by adults with hearing loss is hearing in the presence of background noise.[2] One of the primary features of hearing aids that combats difficulties with hearing in noisy environments is directional processing.

Directional processing, often referred to as directionality, is the ability of the device to prioritize sounds coming from specific directions while suppressing sounds from other directions. Directional processing has been shown to be effective in significantly enhancing speech intelligibility and reducing listening effort in the presence of background noise.[3] When wearing hearing aids that have directional microphones, the user will have better audibility for sound arriving from the front, when compared to sound arriving from the side or behind the same listener.

One method of directional processing is through the use of a dual-omni directional microphone array. A directional response can be achieved by combining the signals of two omnidirectional microphones in a certain way to enhance the signal energy coming from a specific direction while suppressing the noise energy coming from all other directions. For example, let's consider a scenario in which the signal of interest is coming from straight ahead of the hearing aid wearer and noise is coming from behind. When a small delay (in the order of several microseconds) is applied to the front microphone, sounds arriving from behind first arrive at the rear microphone and, several microseconds later, the front microphone. This delay aligns the two microphone signals, which when subtracted together will reduce the level of sounds arriving from behind the listener.

LINK by Eargo ("LINK") is an FDA-registered earbud-style OTC hearing aid that provides directional processing benefits to the user through use of a dual-omni directional microphone array. LINK comes with four preset programs designed for adults with perceived mild to moderate hearing loss as well as several hearing aid and noise management features such as Active Noise Cancellation (ANC), Noise Reduction, Feedback Cancellation, and Directional Processing. LINK supports True Wireless Stereo (TWS) technology and can stream high-fidelity music and make phone calls using Bluetooth 5.3 technology. It also comes with open/closed-style eartips to suit different listening preferences and is rechargeable with up to 9 hours of runtime in hearing aid mode.

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[1] National Institute on Deafness and Other Communication Disorders (NIDCD). National Institute of Health (NIH). Quick Statistics About Hearing. March 2021. Accessed March 2024.

[2] American Speech-Language-Hearing Association. (n.d.). Hearing loss in adults. American Speech-Language-Hearing Association. https://www.asha.org/practice-portal/clinical-topics/hearing-loss/

[3] Desjardins JL. The Effects of Hearing Aid Directional Microphone and Noise Reduction Processing on Listening Effort in Older Adults with Hearing Loss. J Am Acad Audiol. 2016 Jan;27(1):29-41.

The effectiveness of LINK's directional processing algorithm was evaluated in both clinical and acoustic lab environments. For clinical lab testing, the improvements to speech intelligibility with the directionality features turned on (vs. off) in listeners with normal hearing was determined. In this study, normal-hearing listeners were used to evaluate the effectiveness of the directionality feature while minimizing/eliminating inter-subject variability introduced due to variations in hearing loss. The acoustic lab characterization involved measurement of polar plot and computing directivity index in an anechoic space on a Head & Torso Simulator (HATS) Manikin using a turntable.

Protocol and Procedure: Clinical Lab Testing

Participants

Fifteen adult normal-hearing participants were recruited to complete in-lab clinical measurements. Inclusion criteria were as follows: pure tone thresholds of 25 dBHL or better at a defined frequency set (0.5, 1, 2, 3, 4kHz), symmetric pure-tone thresholds (<15 dB difference between ears at any frequency), and had English as a primary spoken language. Participants were asked about their language history. All participants completed otoscopy, air-conduction pure tone audiometry, and aided sound field speech-in-noise measurements. Testing was completed in one session lasting approximately one hour. Participant demographics and average audiograms are shown below.

	N=15
Gender [N (%)]	
Male	9 (60.0)
Female	6 (40.0)
Age (years)	
Range	22-55
Mean (SD)	38.2 (11.2)
Native Language [N (%)]	
Native English Speakers	11 (73.3)
Non-Native English Speakers	4 (26.7)
Language Fluency [N (%)]	
Monolingual English Speakers	5 (33.3)
Bi/Multi-Lingual Speakers	10 (66.7)

Table 1. Participant Demographics

Basic demographics of study participants (N= 15).

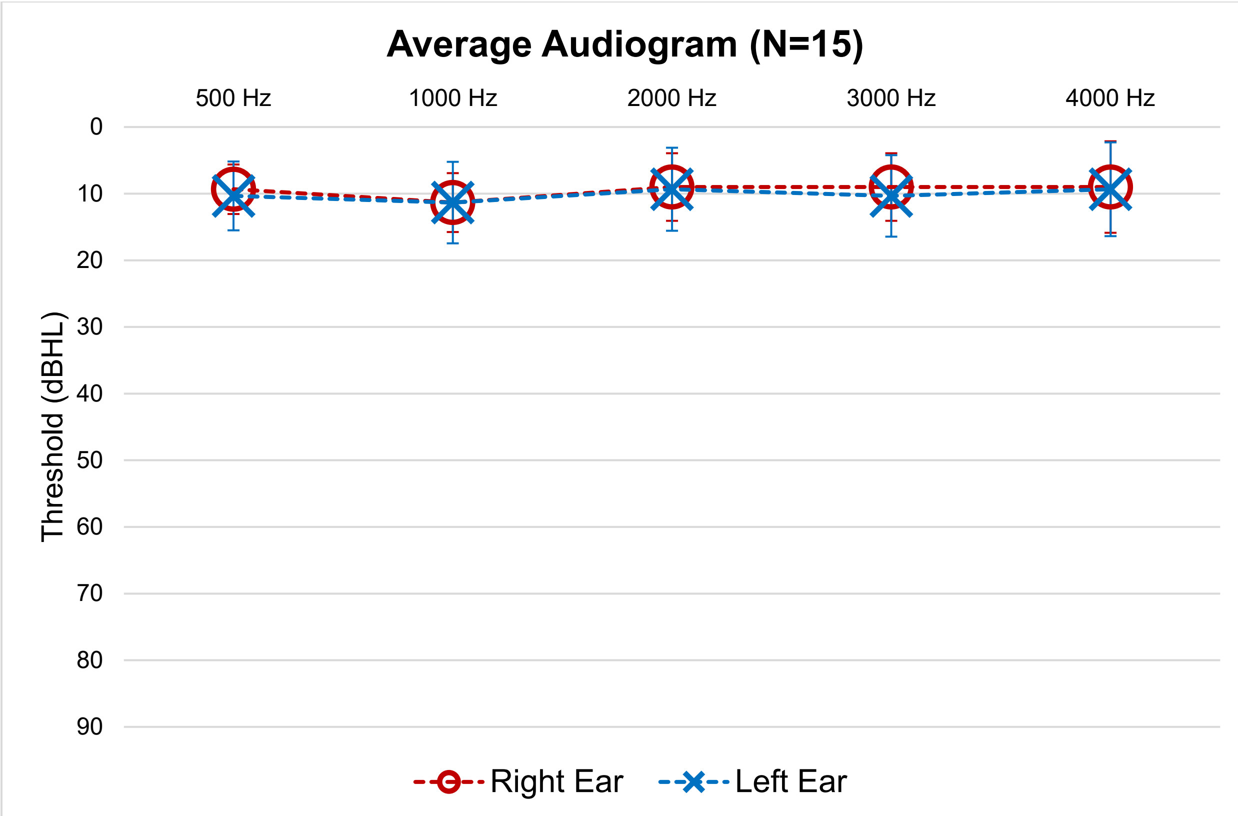

Figure 1. Average Audiogram
Air-conduction thresholds averaged for the participants (N= 15). Error bars represent the standard deviation.

Stimuli and Procedures
Speech-in-noise intelligibility was tested using the Hearing in Noise Test (HINT) stimuli. The HINT materials provide 25 phonemically balanced lists of ten sentences, where the mean-squared level of each digitally recorded sentence was adjusted to equate intelligibility when presented in spectrally matched noise to normal hearing listeners.[4] 15 of these lists were used during our testing. Speech stimuli from the HINT corpora were presented from 0° at 65 dBSPL. Uncorrelated speech-shaped noise was presented from speakers at 45°, 135°, 225°, and 315°. The noise was adjusted to achieve seven signal-to-noise ratio (SNR) conditions (-16, -8, -4, -2, 0, +4 dB). The figure below shows the measurement set up with speech coming through the 0° speaker and the four surrounding speakers creating a diffused noise environment.

[4] Nilsson M, Soli SD, Sullivan JA. Development of the Hearing in Noise Test for the measurement of speech reception thresholds in quiet and in noise. J Acoust Soc. Am. 1994 Feb;95(2):1085–1099.

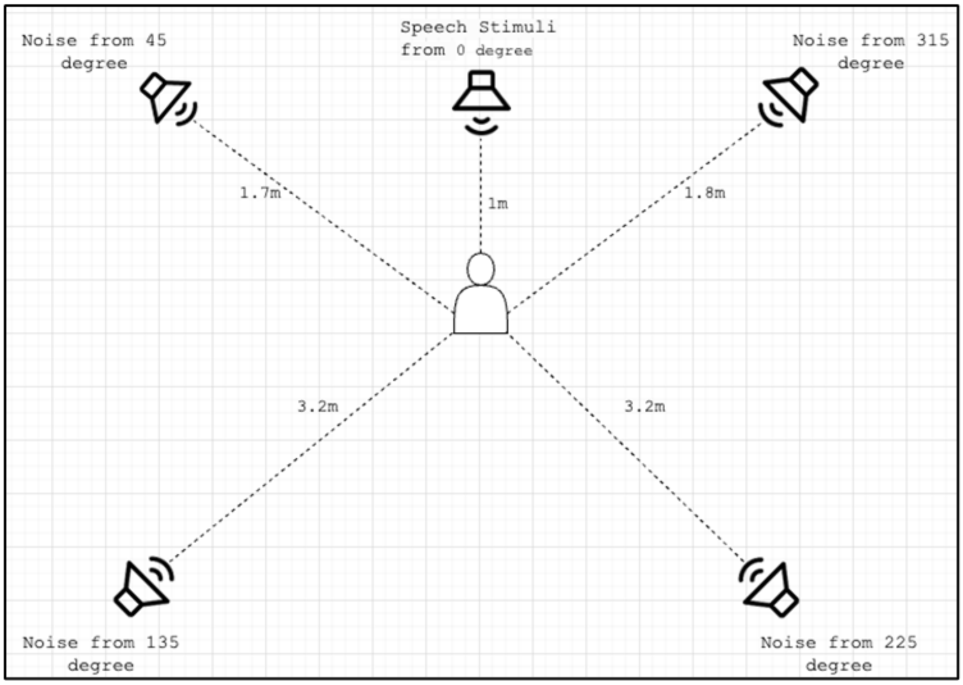

Figure 2. Sound Field Set Up

Sound Field set up showing speech stimuli coming from 0° and uncorrelated speech-shaped noise presented from speakers at 45°, 135°, 225°, and 315°.

During testing, participants wore LINK hearing aids, which were set to a flat mild gain. Two hearing aid states were tested: 1. (baseline state) With directional processing deactivated and 2. With directional processing activated. The order in which participants experienced hearing aid states was randomized; however, each participant completed responses to a list of ten sentences for each of the seven SNR conditions of a given hearing aid state before moving to the set of seven SNR conditions of the next state. The SNR conditions were also randomized within each set of seven. Participants were blind to test conditions.

The participants were instructed that they would be hearing speech from the speaker in front and noise coming from around them and that they should try to repeat back the entire sentence as best as they could. The listener was instructed to respond verbally in the time between each sentence. Each participant first completed a practice list. Scoring was completed simultaneously during testing by the experimenter, author L.P. After every list of ten sentences (representing one SNR condition in a given hearing aid state), the participant was asked a single question about subjective difficulty. At the end of the session, the participant was also asked about overall difficulty between the two hearing aid states.

Results: Clinical Lab Testing

Objective evaluation was completed using speech-in-noise testing in the sound field. For the speech-in-noise test using HINT stimuli, the percent correct is calculated by counting the whole words correctly repeated within the given ten-sentence list. For the baseline condition where directional processing was deactivated, performance was poorest. For the condition where directional processing was activated, performance was best. The performance patterns between both states is expected, as directional processing betters the signal-to-noise ratio for the listener. Average performance across all SNR conditions and test states can be found in *Table 2*.

Test State	SNR Condition						
	-16 dB	**-12 dB**	**-8 dB**	**-4 dB**	**-2 dB**	**0 dB**	**+4 dB**
Directional Processing OFF	2%	10%	42%	56%	97%	96%	100%
[Range]	[0-8%]	[2-32%]	[12-71%]	[17-94%]	[81-100%]	[83-100%]	[98-100%]
Directional Processing ON	12%	47%	83%	98%	99%	100%	100%
[Range]	[0-47%]	[14-76%]	[47-98%]	[80-100%]	[96-100%]	[98-100%]	[100-100%]

Table 2. Average Percent Correct Performance
Average percent correct performance across two test conditions (N= 15).

The group mean psychometric functions derived from the raw speech-in-noise test data are shown in *Figure 3*. Test state differences in performance are apparent throughout the psychometric functions. Also shown are the speech reception thresholds measured at 50% speech intelligibility levels. The SRTs are represented both as improvements in SNR (in dB) and intelligibility (in percent correct). Compared to the baseline state, the SNR improvement noted when directional processing was activated was 5.5dB. Compared to the baseline state, the intelligibility improvement noted when directional processing was activated was 40%. These results demonstrate the benefit of directional processing strategies in improving signal-to-noise ratio and intelligibility when listening to speech in the presence of background noise.

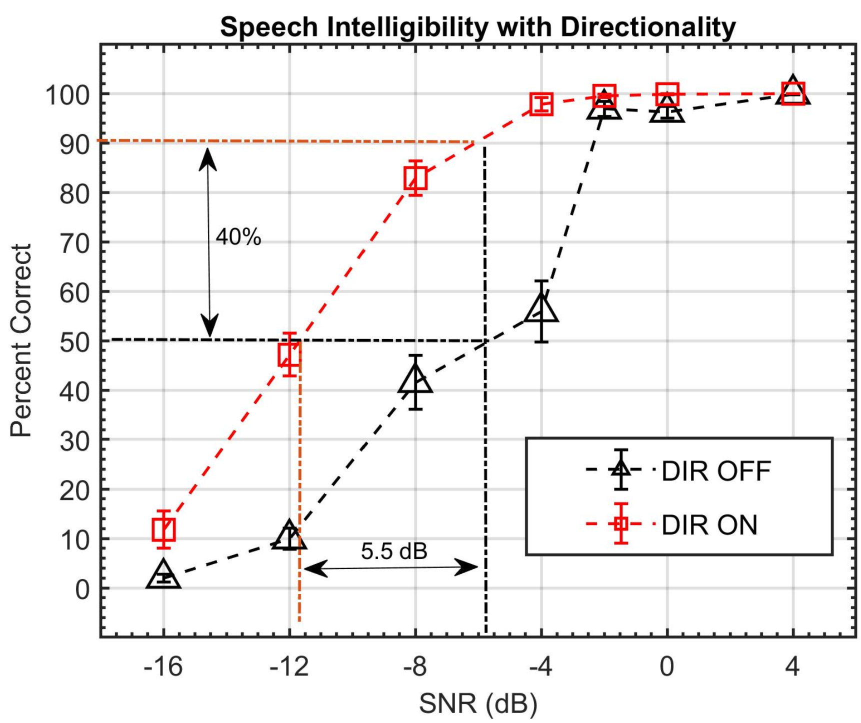

Figure 3. Psychometric Functions Derived from Speech-in-Noise Testing
Mean psychometric functions of each test state. SRT and intelligibility improvements from baseline state noted in dB and percent correct, respectively. (N= 15).

Subjective evaluation was completed by asking participants to rate the subjective difficulty after each SNR condition completed in each test state. After each set, the participant was asked, “How difficult was it for you to understand these sentences?”, with the response options being: “Impossible”, “Very Hard”, “Hard”, “Easy”, and “Very Easy”. *Figures 4a-b* shows the difficulty ratings across each test state and SNR condition. For the baseline condition where directional processing was deactivated, difficulty ratings were highest. For the condition where directional processing was activated, difficulty ratings were lowest. The performance patterns across both states is as expected, with the presence of directional processing leading to increased ease of listening.

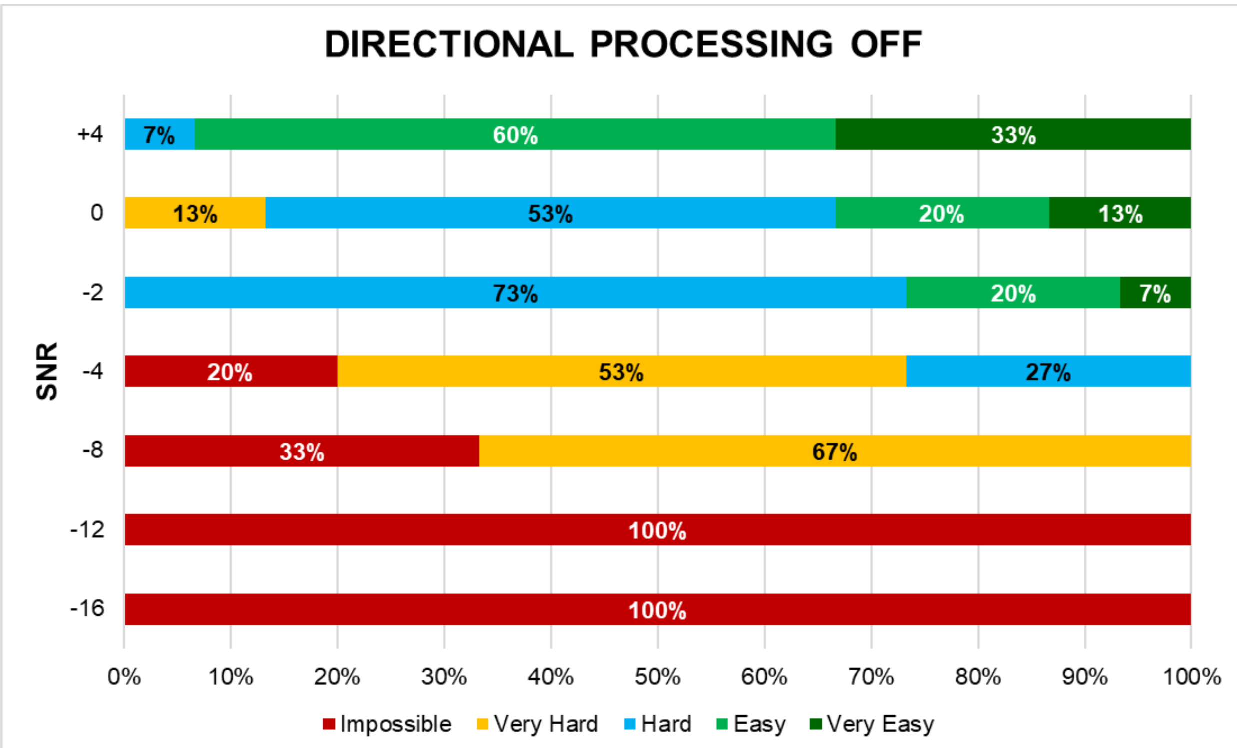

Figure 4a. Subjective Difficulty Ratings in Baseline Test State
Subjective difficulty ratings show for the baseline state where directional processing was off (N= 15).

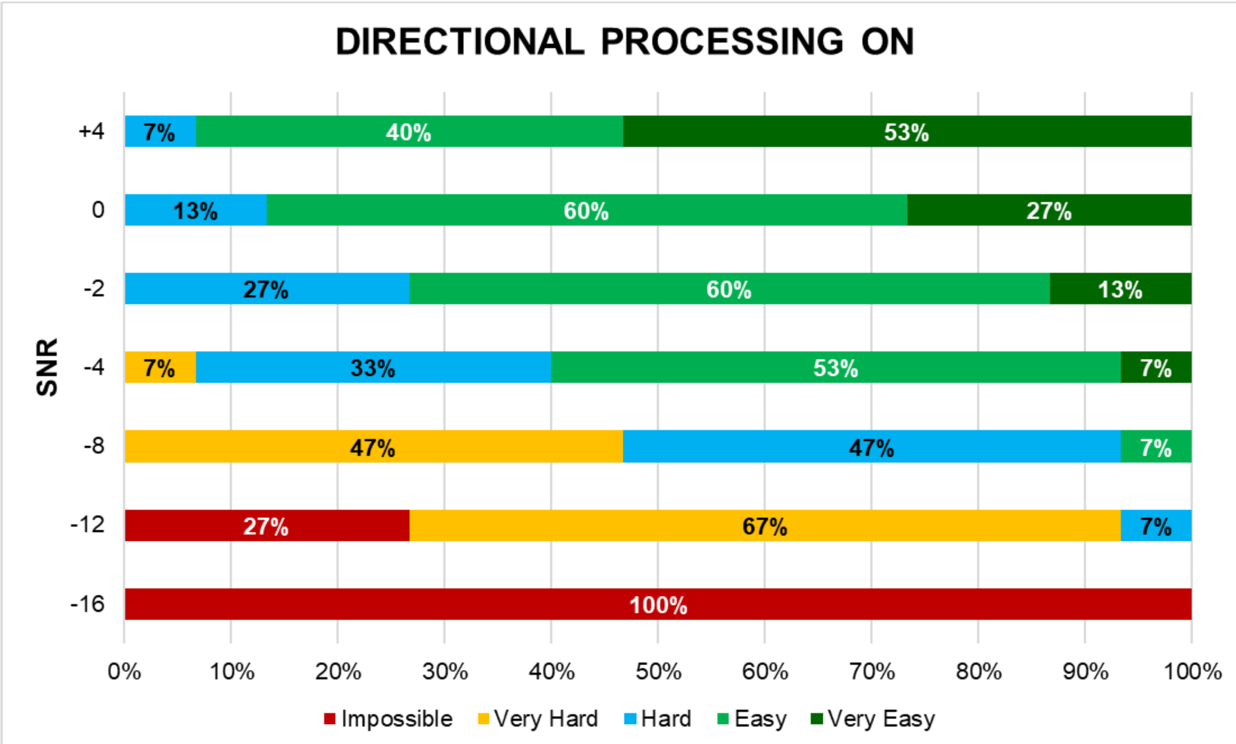

Figure 4b. Subjective Difficulty Ratings in Test State 2
Subjective difficulty ratings show for test state 2 where directional processing was on (N= 15).

Overall subjective evaluation was completed by asking the participant to rank their preference and difficulty level of each test state after all testing was completed. Subjective preferences are noted in *Table 3*, clearly revealing the baseline as the most difficult state and the state in which directional processing is activated to be the easiest. These results not only support the objective benefits noted in acoustic lab testing, but also reinforce the subjective benefit of reduced listening effort when directional processing strategies are activated.

	Test State	
	Directional Processing OFF	Directional Processing ON
Easiest/ Most Preferred % (N)	0.0% (0)	**100% (15)**

Table 3. Subjective Test State Difficulty
Subjective difficulty reported by participants at the conclusion of testing (N=15).

Protocol, Procedure, and Results: Acoustic Lab Testing

The objective of this test was to measure the directional characteristics of the LINK device. Directional characteristics of the LINK device were measured on a HATS Manikin in an anechoic lab environment to ensure accurate, reliable, and repeated measurements. The reference microphone, ear simulators, and sound source were calibrated before beginning the measurement. The HATS Manikin was placed on a turn-table to facilitate measurements at different angular orientations. The LINK devices were positioned on the left and right ears of the HATS Manikin. A sinusoidal sweep from 100Hz – 8KHz at calibrated level of 75 dBSPL is played from the sound source, while the HATS was directly facing the sound source at 0°. Figure 5 below illustrates the setup used to measure directionality on LINK devices.

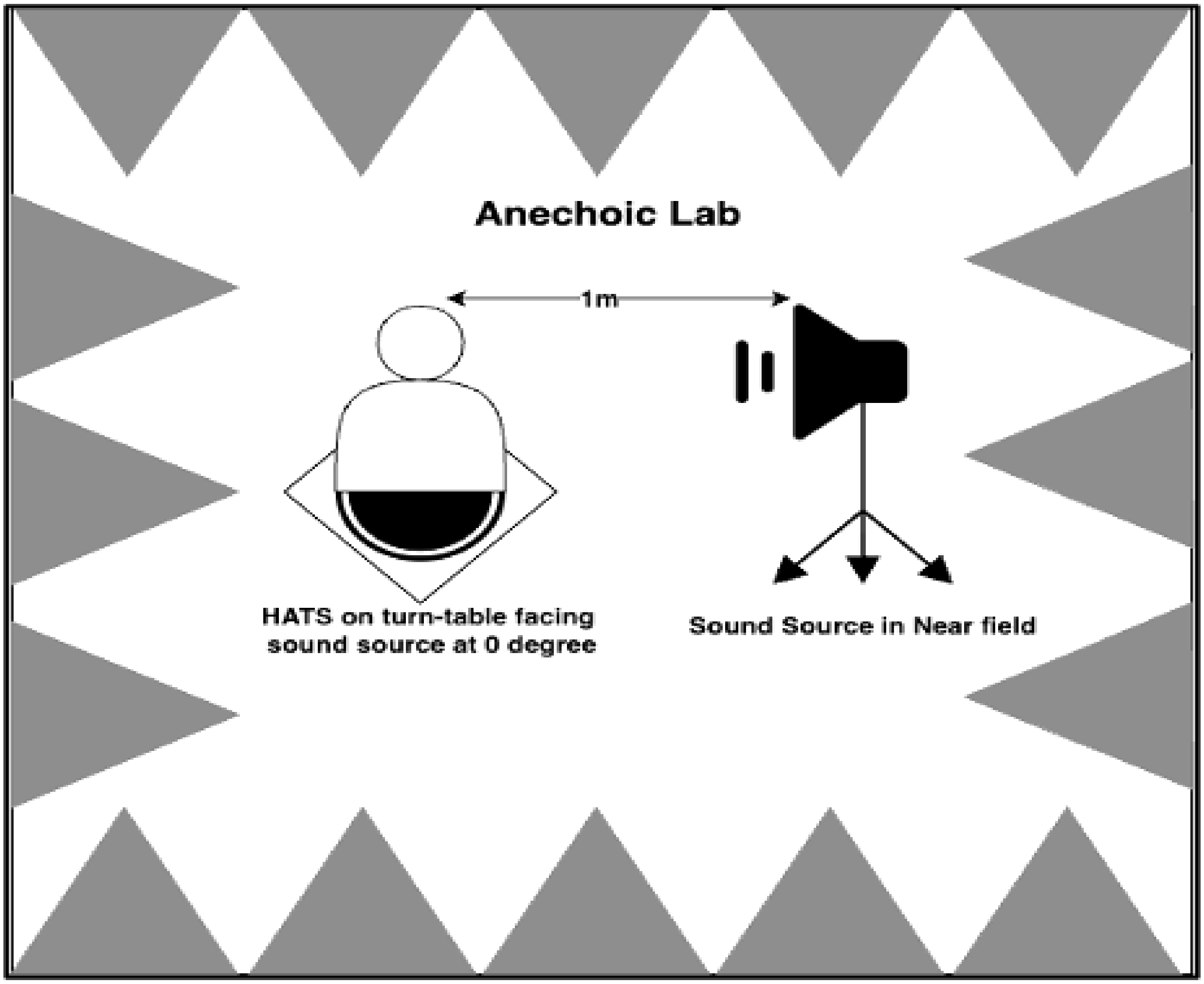

Figure 5. LINK by Eargo Directionality Measurement Test Setup

The test was then repeated by playing the same sinusoidal signal while the HATS, positioned on the turn-table, was incrementally rotated by 10° increments. Sensitivity data was captured for each 10° rotation. This data represents the response of the LINK devices at each 10° increment from 0° to 360° on both left and right ear. The captured data was then processed to generate a polar plot showing the sensitivity of the LINK device at various angles across all test frequencies.

The LINK device response was quantified in two ways, first by analyzing the polar plots and calculating the directivity index (DI). A polar plot is a graphical representation of a microphone's directional sensitivity across different angles relative to the microphone's axis. It illustrates the amount of attenuation at different angles. The sensitivity or gain of the microphone is typically represented in dB on the vertical axis, while the circular axis represents the angle around the microphone, ranging from 0° to 360°. Straight ahead and pointing up is 0°, to the left and right are +/- 90°, and 180° is directly behind the microphone.

The polar plot below (Figure 6) shows the sensitivity of the LINK device across different frequencies and at various angles. As can be seen, the LINK device is most sensitive to sounds coming from the front and less sensitive to sound coming from other angles.

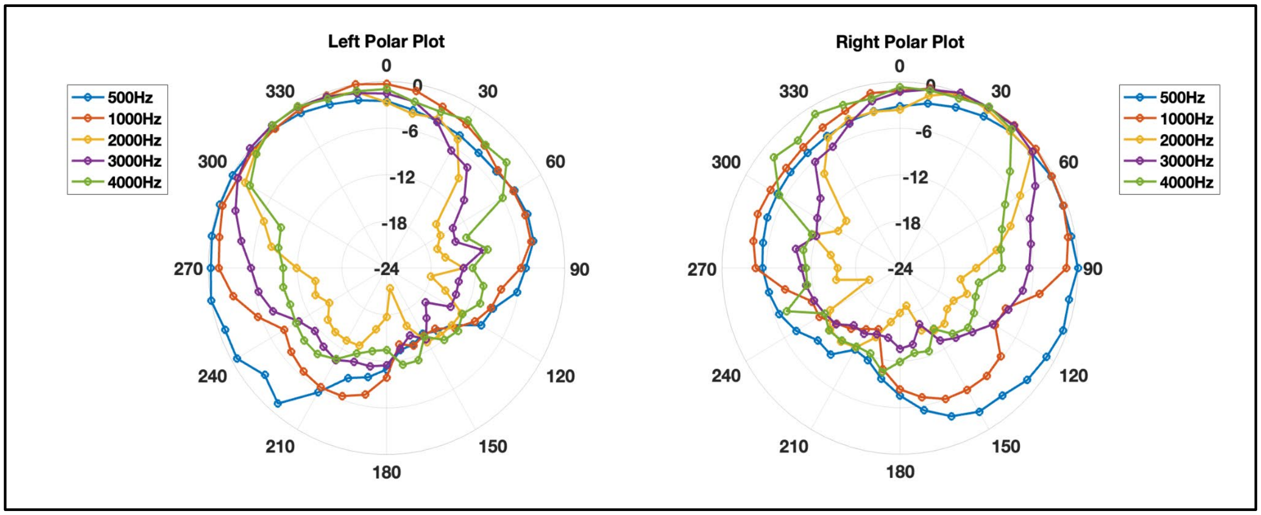

Figure 6. LINK by Eargo Directionality Polar Plots for left and right devices placed on the HATS manikin.

The LINK device response was quantified in a second way, by calculating the directivity index (DI). Directivity Index[5],[6] is the amount of noise field attenuation provided by different polar plot patterns. A microphone or microphone array's DI is a measure of how directional a microphone is, which, behaviorally, can be interpreted as an effective improvement in signal-to-noise ratio. The more the directional microphone attenuates sound at angles other than zero degrees, the higher the DI is. Microphone DI is measured in dB as the ratio of microphone output for a given input that arrives from directly in front of the microphone to an acoustic input that arrives equally from all directions around the microphone—referred to as a diffuse sound source. By definition, omnidirectional microphones have a DI of 0dB, meaning they produce the same output whether the input is concentrated at one angle or spread to all angles. Directional microphones with just two sound inlets can have a DI of up to 6dB[7].

Directivity Index is calculated using the following formula[8] :

[5] Beranek LL. Acoustics. New York: McGraw-Hill Electrical and Electronic Engineering Series, McGraw Hill; 1954

[6] American National Standards Institute (2010). "ANSI S3.35-2010 Method of Measurement of Performance Characteristics of Hearing Aids Under Simulated Real-Ear Working Conditions." American National Standard S3.35: 17-38.

[7] Elko, G.W. (2000). Superdirectional microphone arrays. In S.L. Gay & J. Benesty (Eds.), Acoustic signal processing for telecommunication, (Chapter 10, pp. 181-237). Kluwer Academic Publishers.

[8] American National Standards Institute/ Acoustical Society of America (2010). "ANSI/ASA S3.35-2021: Method of measurement of performance characteristics of hearing aids under simulated real-ear working conditions." American National Standard S3.35.

$$D_P = 10\log_{10}\left(\frac{1}{\frac{\pi}{2n}\sum_{j=1}^{n}10^{R(0,\theta_j)/10}\left|\sin\theta_j\right|}\right)$$

Figure 7: Directivity Index - ANSI-ASA S3.35 Standard.

where

Dp = Directivity Index
n = number of angles of sound incidence
j = integer indexing the angles of sound incidence
θ_j = is (j -1), the angle indexed by j [in degrees]
R = directional response at indicated angle in dB

The figure below illustrates the directivity index of the LINK across frequencies. The average directivity index across frequencies for both the left and right ear was 5dB.

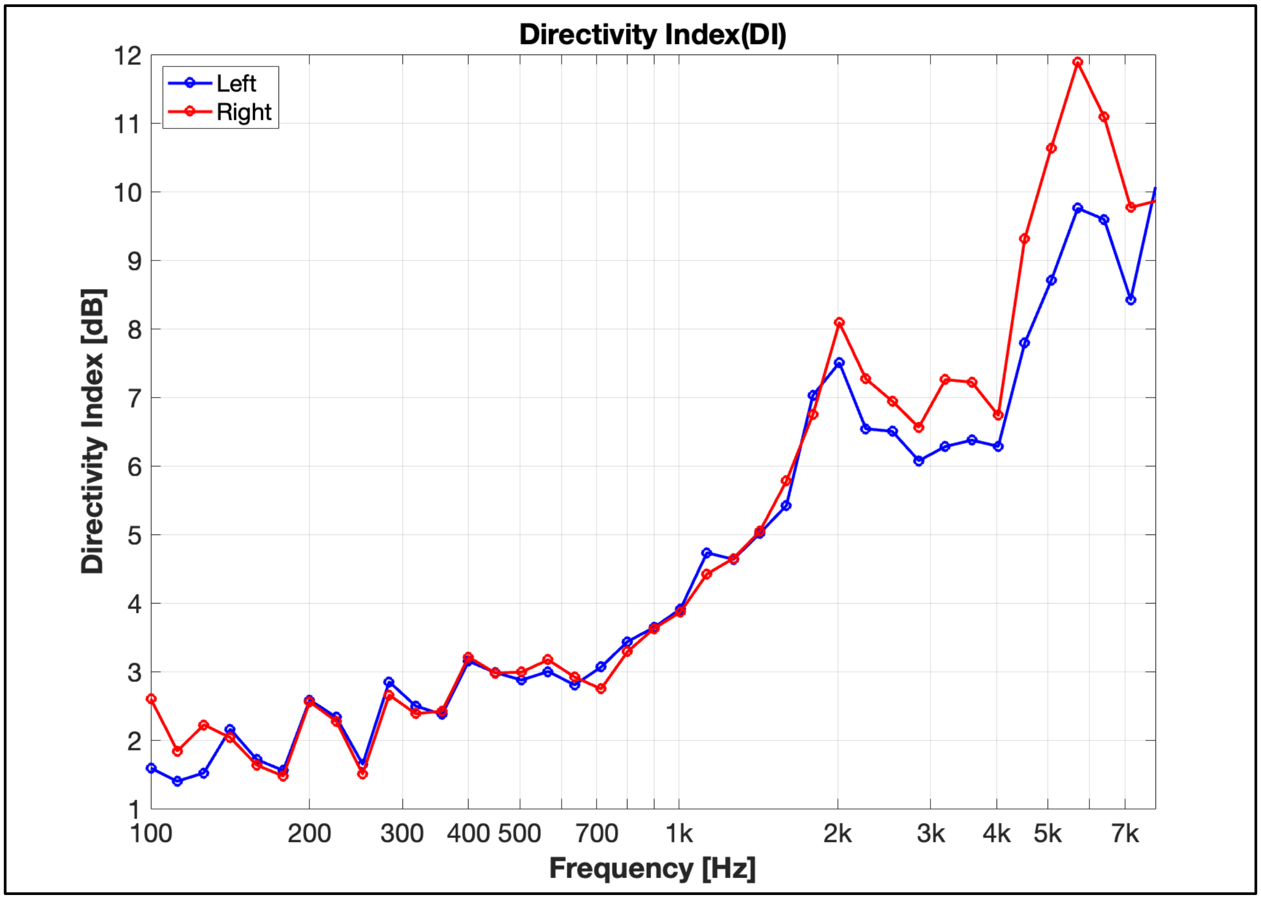

Figure 8. LINK by Eargo Directionality Index (DI)

Discussion

In this study an investigation of the efficacy of the directional processing performance of the LINK by Eargo device was conducted. Acoustic lab test results were undertaken to investigate the objective benefit of LINK directional processing. Objectively, after analyzing the polar plots generated from HATS turntable measurements, there is clear evidence that the LINK devices show strongest sensitivity to sounds coming from the front with attenuation coming from other angles. The directivity index measured across a broad frequency range averages to 5dB, demonstrating a significant directional benefit using a dual-omni microphone strategy. As illustrated by the polar plots and the DI values across frequencies, the LINK product shows efficacious directional processing function.

After confirming significant benefit through standard acoustic measures, this study then took steps to investigate whether benefits could be shown on-ear. Objectively, users were found to have an average of 5.5dB of SNR benefit and 40% increased intelligibility benefit when utilizing directional processing. This demonstrates significant performance enhancement when listening to speech in a dynamic environment. Subjectively, users were unanimous in their preference for using devices with active directional processing versus using devices without directional processing when listening to speech in a noisy environment. This suggests the listening burden can be significantly decreased when utilizing advanced features, such as directional processing. Taken together, the end-user experience is shown to be greatly improved when using the LINK by Eargo devices, with directional processing activated, when attempting to hear well in a noisy environment.

Conclusion

Hearing in the presence of background noise continues to be the most difficult situation for those with hearing loss. Utilizing hearing aids that have effective directional processing capabilities can significantly reduce the burden placed on those with hearing loss. This validation and verification study found that the LINK by Eargo directional processing strategy resulted in an average of 5.5dB SNR improvement with objective acoustic testing and an average of 40% intelligibility improvement during clinical testing with listeners with normal hearing. Taken together, it is clear that the LINK by Eargo product gives the user a clear and distinct advantage when trying to comprehend speech in dynamic noisy environments.