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Research Note

Noise Exposure and Background Noise Tolerance in Listeners With Normal Audiograms

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Purpose: Tolerance for background noise when listening to speech has been found to vary greatly between individuals, despite clinically similar audiograms. Recent work suggests that listeners at risk for noise-induced hearing loss (NIHL) self-report greater annoyance of background sounds compared with listeners at lower risk for NIHL. To date, the relationship between noise exposure levels and background noise tolerance has not been studied using objective noise exposure level measurements and quantitative (i.e., not questionnaire-based) background noise tolerance measures.
Method: Acceptable Noise Level (ANL; Nabelek, Tucker, & Letowski, 1991) scores and week-long noise dosimetry measurements were obtained for 56 normal-hearing college students, 22 of whom were routinely exposed to levels of noise that exceed recommended exposure limits (higher risk). The remaining 34 participants did not exceed recommended exposure limits (lower risk).
Results: The lower risk group's average daily noise dose was 26%, whereas the higher risk group accrued an average daily noise dose of 461%. The lower risk group was found to be more tolerant of background noise than the higher risk group, with mean ANL scores of 3.1 dB and 5.4 dB signal-to-noise ratio, respectively. A small but statistically significant relationship between ANL and noise dose was found, indicating that higher levels of noise exposure were associated with lower background noise tolerance.
Conclusions: Results suggest that young adults at higher risk for NIHL based on objective noise exposure data have a slightly lower tolerance for background noise when listening to speech. These findings open avenues for future work on background noise tolerance in more diverse noise-exposed populations.

Listener tolerance for background noise while listening to running speech, even among listeners with similar demographics and hearing thresholds, is not uniform. Various methods of measuring background noise tolerance have been developed that reveal this intersubject variability (Liberman, Epstein, Cleveland, Wang, & Maison, 2016; Nabelek, Tampas, & Burchfield, 2004; Nabelek, Tucker, & Letowski, 1991), from questionnaires to more quantitative measures, such as the Acceptable Noise Level (ANL) test (Nabelek et al., 1991). In the ANL test, the examiner finds the listener's most comfortable level (MCL) for listening to a recorded speech passage. Following the establishment of MCL, the examiner adjusts the intensity of a competing speech babble background noise to find the highest background noise level (BNL) the listener will tolerate without becoming fatigued or stressed while following the passage. The ANL is defined as the difference in dB between the MCL and BNL (ANL = MCL - BNL), or, in other words, the lowest signal-to-noise ratio (SNR) the listener will tolerate while still following the passage. Higher ANL scores reflect a lower tolerance for background noise.

Previous work suggests that ANL is not influenced by the listener age, sex, (Nabelek et al., 1991, 2004; Rogers, Harkrider, Burchfield, & Nabelek, 2003), or loudness judgments (Franklin, White, & Franklin, 2012; Franklin, White, Franklin, & Livengood, 2016). However, there are equivocal findings with respect to its relationship with hearing sensitivity (Brännström & Østergaard Olsen, 2017; Nabelek, Freyaldenhoven, Tampas, Burchfield, & Muenchen, 2006; Nabelek et al., 1991). A handful of studies suggest that the intelligibility of the speech passage may influence ANL scores (Gordon-Hickey & Moore, 2008; Gordon-Hickey & Morlas, 2015; Koch, Dingemanse, Goedegebure, & Janse,

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2016; Recker & Micheyl, 2017) despite a lack of correlation between ANL and clinical tests of speech perception in noise (Harkrider & Smith, 2005; Koch et al., 2016; Nabelek et al., 2004, 2006; von Hapsburg & Bahng, 2006).

To our knowledge, only one previous study has focused on the relationship between ANL and the listeners' noise exposure patterns. In young adults with normal hearing, Franklin, White, Franklin, and Smith-Olinde (2014) objectively measured the amount of time a listener spent in different listening environments using a data-logging device that utilized the auditory scene analysis technology common in modern day hearing aids. They found that listeners with higher tolerance for background noise (lower ANL scores) spent more time in environments where a competing sound (i.e., background noise) was present than listeners with lower background noise tolerance, who spent more time in quiet environments. However, when environment sound levels were compared, the high- and low-ANL groups were not found to be different, and both groups had noise exposure levels consistent with being at lower risk for noise-induced hearing loss (NIHL). It is, therefore, currently unknown whether ANL scores are different between listeners who are at lower versus higher risk for NIHL.

There has been increasing interest in how exposure to loud noise affects behavioral and neurophysiological measures of auditory system function before NIHL is evident on the audiogram. It has been proposed that routine exposure to loud noise may be responsible for suprathreshold perceptual difficulties in listeners with normal audiograms, including complaints of difficulty understanding and tolerating speech in background noise (Liberman et al., 2016; Plack, Barker, & Prendergast, 2014). The goal of the current study was to extend this line of "hidden hearing loss" research by comparing background noise tolerance between listeners at lower and higher risk for NIHL. The closest study to consider the link between behavioral tolerance for sound and risk for NIHL is by Liberman et al. (2016). On a questionnaire, they found that young adults with routine exposure to loud sounds but normal audiograms self-reported greater annoyance and avoidance of distracting sounds (e.g., baby crying, dishes clanking) than a lower risk group that was matched to the higher risk group in regards to age and hearing thresholds in the standard audiometric range. This group difference is suggestive of decreased sound tolerance in young adult populations routinely exposed to high-intensity sounds; however, because the questionnaire did not specifically ask about tolerance for background noise, results cannot be generalized to the ANL test. To more directly investigate the effect of high levels of noise exposure on background noise tolerance, we used an objective measure of noise exposure via dosimetry and a quantitative assessment of background noise tolerance via the ANL test. The findings observed in the Liberman et al. study lead us to predict that young adult listeners who may be at risk for NIHL due to high levels of routine noise exposure would be less tolerant of background noise while listening to speech (higher ANL scores) than peers with lower routine noise exposure.

Method

College students between the ages of 18 and 24 years with no history of neurological or audiological disorders were recruited through the University of Connecticut's Daily Digest announcement e-mail and word of mouth to participate in a study investigating subclinical hearing loss in noise-exposed, college-aged students. Our recruitment efforts targeted young adults with clinically normal hearing who were actively participating in college music ensembles and who, by virtue of their routine exposure to high noise levels, may be at risk for NIHL. Data collection occurred over the course of 1 week for each participant during the academic semester. A test battery including audiometry and ANL (Frye Electronics, Inc.) assessment was administered in a single-walled, sound-attenuating chamber on Day 1 of the experiment. Participants were asked to refrain from any loud activities for the 14 hr preceding the test session to minimize the possibility of testing participants while they were experiencing a temporary threshold shift. Following the test session, participants began 7-day continuous noise dosimetry. The current analysis focuses on a subset of 56 participants (44 females) who met the criteria of having clinically normal hearing ($\leq$ 25 dB HL thresholds from 250 to 8000 Hz), three trials of ANL, clinically normal Quick Speech-in-Noise (QuickSIN) scores (< 3–dB SNR Loss; Etymotic Research, Inc.), and were native speakers of English.

The study was approved by the Institutional Review Board at the University of Connecticut. Prior to starting the experiment, written consent was obtained from all participants. Participants received financial compensation for their participation in this weeklong study.

Hearing Thresholds

Pure-tone air-conduction thresholds were obtained bilaterally at octave and semioctave frequencies from 125 to 8000 Hz using ER-2 insert earphones connected to a Grason-Stadler GSI 61 audiometer. All participants included in the current analyses were negative for conductive pathology.

Noise Exposure

To objectively assess noise exposure, all participants wore Etymotic ER-200DW8 personal noise dosimeters for seven 24-hr days to continuously record noise levels in their environment. Dosimeters were set to the National Institute for Occupational Safety and Health (NIOSH, 1998) criteria (85-dB[A] criterion level, 3-dB exchange rate, with 75-dB[A] threshold), and calibration checks were performed periodically. The noise dose for each 24-hr measurement day was calculated, and doses were averaged across days to derive the average daily noise exposure dose used in our statistical analysis. Please see Tufts and Skoe (2018) for an in-depth description of this dosimetry methodology. Note that in the context of dosimetry, "noise" includes all sounds present in an environment.

Background Noise Tolerance

The ANL test materials use the Arizona Travelogue (Cosmos, Inc.), a speech passage spoken by a man, as the target speech signal and a 12-talker speech babble as background noise. The test was delivered from a CD (Frye Electronics, Inc.) via a GSI 61 audiometer to a single speaker located in the sound booth. Participants were seated 1 m from the speaker at 0° azimuth, and they were verbally instructed using instructions adapted from Nabelek et al. (2004). To find the MCL for the speech passage, the experimenter increased the level of the speech passage from 30 dB HL in 5-dB steps until the participant signaled to the experimenter that the MCL had been reached. To find the BNL, the speech passage was played at the MCL and the level of the background babble was increased from 30 dB HL in 5-dB steps and bracketed in 2-dB steps until the participant signaled that the maximum amount of background noise she/he was willing to tolerate while following the speech passage had been reached. The ANL score was calculated as the difference between the MCL and BNL. This entire procedure was completed three times, and the average ANL score of these three trials was used in the analysis. The test developers' written instructions for the participant define ANL as a measure of how much background noise the listener "would be willing to accept or 'put up with' [i.e., tolerate] without becoming tense or tired while… following the story" (Nabelek et al., 2004). The test developers acknowledge that the term *tolerance* is often associated with loudness discomfort levels and that it is also used to describe hyperacusis. We have therefore chosen the term *background noise tolerance* to describe the specific aspect of tolerance being measured by ANL.

Participant Groups

Participants were divided into two groups based on their average daily noise dose (Figure 1A). The higher risk group included 22 participants (18 females) who accrued daily average noise doses > 100%, 16 of whom were in music ensembles at the time of testing. The lower risk group (n = 34, 26 females) included participants with ≤ 100% noise dose, of which seven were actively involved in music ensembles at the time of test. The noise dose of the lower risk group ranged from 1% to 97% (M = 26%, SD = 22%, Mdn = 20%), with both measures of center falling well below the NIOSH-recommended exposure limit of 100%. By contrast, the higher risk group had doses ranging from 107% to 902% (M = 461%, SD = 289%, Mdn = 359%). The lower and higher risk groups were matched with respect to age (U = 303, p = .23) and 10-frequency pure-tone hearing threshold averages (i.e., the average of the thresholds for all 10 octave and semioctave frequencies from 125 to 8000 Hz) for both right (U = 351, p = .69) and left ears (U = 321, p = .37). For the lower risk group, the median pure-tone average (PTA) was 5.0 dB HL (−0.50 to 11.5 dB HL) for the right ear and 6.0 dB HL (−0.5 to 11.0 dB HL) for the left ear. For the higher risk group, the median PTA was 5.8 dB HL (0 to 15.0 dB HL) for the right ear and 5.3 dB HL (0 to 14.0 dB HL) for the left ear (Figure 1D). The groups were also matched on the QuickSIN (U = 338, p = .54; Figure 1C). QuickSIN is used to measure speech recognition in noise ability. The final score is reported as "SNR Loss," which is derived from the number of key words a listener correctly repeats from sentences presented with increasing levels of background babble (Killion, Niquette, Gudmundsen, Revit, & Banerjee, 2004). For the lower risk group, the mean QuickSIN SNR loss ranged from −1.3 to 2.0 dB (M = 0.67 dB, SD = 0.77 dB, Mdn = 0.75 dB). For the high-risk group, the mean QuickSIN SNR loss ranged from −0.25 to 3.0 dB (M = 0.90 dB, SD = 0.80 dB, Mdn = 0.90 dB). An SNR loss < 3 dB is considered clinically normal (Etymotic Research, Inc.).

Statistical Analysis

Statistical analysis was completed using IBM SPSS Statistics 24. To compare the groups, independent-samples Mann–Whitney U tests were performed on PTA, age, QuickSIN score, average ANL, and years of musical training. Spearman correlations were performed between ANL and two dependent measures: noise dose and years of musical training. Nonparametric tests were performed given that the variables for noise dose and QuickSIN did not meet the Kolmogorov–Smirnov test for normality (Dose: 0.27, 56, p < .001; QuickSIN: 0.15, 56, p = .004).

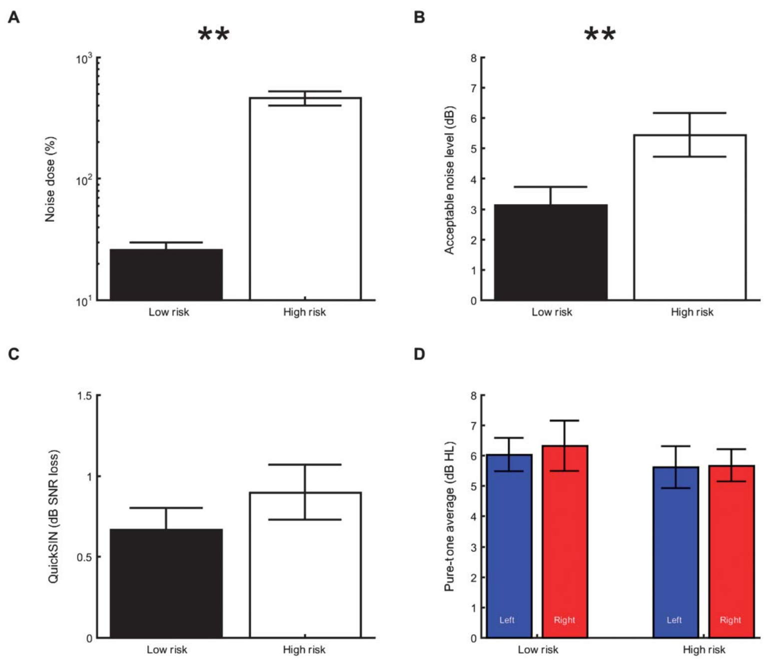
Results

Both groups' average ANLs fell within what is considered to be the low ANL range (< 7 dB; Nabelek et al., 2006); however, the ANL scores of the two groups still differed significantly (U = 230, p = .015), with the higher risk group being less tolerant of background noise than the lower risk group (Figure 1B). The median ANL score for the lower risk group was 2.7 dB (M = 3.1 dB, SD = 3.5 dB), ranging from −3.33 to 12.0 dB. The median ANL for the higher risk group was 5.3 dB (M = 5.4 dB, SD = 3.33 dB), ranging from 0 to 14.0 dB.

The relationship between noise dose and ANL was further assessed by treating the data set of 56 participants continuously (i.e., without regard to group membership). There was a significant, albeit weak, correlation between ANL score and noise dose (rho = 0.28, p = .037), with greater levels of noise exposure being associated with lower tolerance for background noise (Figure 2A).

Because a larger portion (73%) of the higher risk group was involved in music ensembles at the time of testing than the lower risk group (21%), analyses were also performed with participants grouped based on music ensemble participation. This analysis revealed that music-ensemble participants were less tolerant of background noise than the group who were not active in music ensembles (U = 219, p = .007). Given that music activities are a primary contributor to the high levels of noise exposure in our data

Figure 1. (A) Individuals in the higher risk group have significantly higher noise doses than those in the lower risk group. (B) The higher risk group has significantly higher Acceptable Noise Level scores, indicative of lower background noise tolerance, than those of the lower risk group. (C) The groups are matched on speech perception in noise, as assessed by the Quick Speech-in-Noise (QuickSIN) test. (D) Lower and higher risk groups are matched on 10-frequency pure-tone averages for both left and right ears. Plots marked with ** indicate $p < .01$. Error bars represent 1 SEM. *SNR* = signal-to-noise ratio.

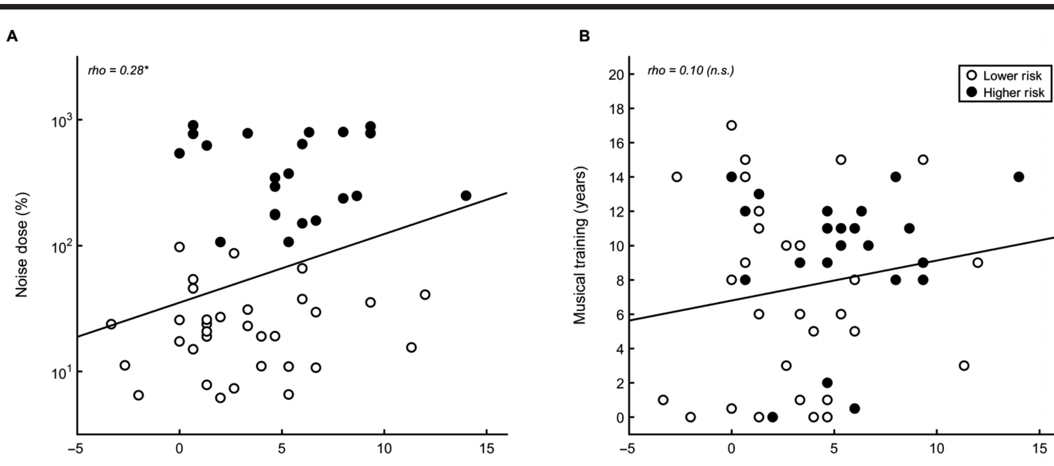


set, it is not surprising that the two grouping strategies yielded similar outcomes. However, when treating musical training as a continuous variable, no significant relationship between years of musical training and ANL was observed (rho = .10, p = .45; Figure 2B), implying that noise exposure and not a history of musical training is contributing to the ANL group differences. We consider the complex relationship between musical training and hearing in noise in a separate paper (see Skoe, Camera, & Tufts, 2018).

Discussion

This study investigated the relationship between background noise tolerance and noise exposure in college

Figure 2. Higher Acceptable Noise Level scores, which indicate lower background noise tolerance, are not associated with years of musical training (B) but are associated with higher noise dose (A). Plot marked with * indicates $p < .05$.



students with clinically normal audiograms and a wide range of noise exposures. We predicted that young adults who are regularly exposed to high-intensity noise would be less tolerant of background noise while listening to running speech than their peers with lower routine noise exposure. The observed group difference in background noise tolerance suggests that listeners with higher risk for NIHL prefer larger SNRs (an increase of 2.3 dB SNR on average) when listening to speech in background noise compared to listeners at lower risk, despite having matched hearing thresholds in the standard audiometric frequency range and similar speech understanding in noise. This gap in ANL scores between the lower and higher risk groups suggests that the higher risk group may be exerting more listening effort than the lower risk group to achieve similar QuickSIN scores, raising the possibility that background noise tolerance might be more sensitive to subclinical hearing loss than tests of speech perception in noise. Recent work suggests that the early stages of noise damage are accompanied by elevated high-frequency thresholds (Liberman et al., 2016). The current study, however, did not measure extended high-frequency thresholds, and so, we cannot say whether the higher risk group had elevated high-frequency thresholds compared to those of the lower risk group for frequencies above 8 kHz.

The Liberman et al. (2016) study, which included behavioral and electrophysiological measurements of auditory function, points to the possibility that decreased sound tolerance is the consequence of noise-induced damage, as inferred from poorer high-frequency audiometric thresholds and decreased cochlear output as measured by electrocochleography. We offer a similar interpretation for our findings, namely, that decreased tolerance for background noise observed in our young adult group at higher risk for NIHL is a reflection of subclinical damage to the auditory system, with candidate mechanisms including cochlear synaptopathy (Furman, Kujawa, & Liberman, 2013; Plack et al., 2014) and changes in central auditory gain (Chambers et al., 2016; Harkrider & Tampas, 2006; Kliuchko, Heinonen-Guzejev, Vuust, Tervaniemi, & Brattico, 2016; Möhrle et al., 2016). Although the 2.3-dB difference in ANL scores found between our lower and higher risk groups is below the level that is considered a minimal clinically important difference (Olsen & Brännström, 2014; Olsen, Lantz, Nielsen, & Brännström, 2012; Olsen, Nielsen, Lantz, & Brännström, 2012), such a small, but significant, group difference is pertinent in the search of “hidden hearing loss” benchmarks, which by definition are below clinically significant criteria. Our results, therefore, suggest that ANL may provide an index of early noise-induced changes to the auditory system that can be utilized in hearing screenings, broadening ANL’s clinical use beyond a predictor of hearing aid success (Nabelek et al., 1991, 2004, 2006).

In the current study, continuous noise dosimetry data were gathered over a full week to capture noise exposure levels (and risk for NIHL) accrued during participants’ typical routines during the academic year. Anecdotal reports suggest that many students maintain their weekly schedule throughout a semester and that some students, especially those who continue with extracurricular activities such as music ensembles, have similar schedules throughout their undergraduate careers. This leads us to treat our measure of noise dose as a representative snapshot of the participants’ typical noise exposure patterns. However, because of the test order (i.e., dosimetry commenced after the ANL) and the descriptive nature of the study, we cannot interpret the ANL scores as having been directly influenced by noise exposure accrued during the period of study enrollment, nor can we claim that the dosimetry data fully accounts for all individual variation in the ANL scores. Indeed, noise exposure explained only 8% of the variance in ANL scores in our sample. Longitudinal designs with testing before and after noise exposure, measured both objectively via noise dosimetry and subjectively via surveys or interviews, would be particularly valuable in delineating relationships between environmental factors, subclinical stages of NIHL, and background noise tolerance. If high levels of noise exposure relate to decreased tolerance for background noise, as suggested by our results, continued long-term routine exposure necessitated by occupation or recreational activities could further reduce the amount of background noise an individual is willing to accept. As suggested by work relating decreased background noise tolerance to decreased hearing aid success (Nabelek et al., 1991, 2004, 2006), this decreased tolerance of background noise may, in turn, influence a listener’s success rate with hearing aids, if and when the hearing damage becomes clinically significant.

Future work on noise exposure and background noise tolerance should also broaden the study sample to include a greater array of sources of noise exposure and a wider age range, as the majority of the higher risk group in our study was recruited from collegiate music ensembles. We adopted this recruitment strategy because of the well-established literature showing that musicians, especially those that perform in large groups, are exposed to high noise levels on a routine basis (Holland, 2008; Miller, Stewart, & Lehman, 2007; Parra, Torres, Lloret, Campos, & Bosh, 2018; Phillips, Henrich, & Mace, 2010). Yet, we found no statistically significant relationship between ANL and years of musical training, suggesting that musical training does not directly influence ANL but instead acts as a “delivery system” for noise. That said, the high degree of overlap between musicianship and risk status is a limitation of our study, both in terms of generalizing to other at-risk populations and examining how musical training influences ANL scores. The influence of musical training on ANL could be examined more directly by using groups matched on noise exposure, but differing in music training histories.

Conclusions

This study aimed to investigate whether higher routine noise exposure is associated with lower background noise tolerance, measured quantitatively using the ANL test. Participants with average daily noise doses above the NIOSH-recommended 100% limit were slightly less accepting of background noise on average than those with less than

100% noise doses. A weak but significant correlation between noise dose and ANL was found, implying that routine noise exposure may be one factor contributing to an individual's tolerance for background noise while listening to speech. Further investigations into the clinical implications of this finding for early identification of noise-induced changes to auditory function are warranted. Our findings provide another data point that music students and other individuals at risk for NIHL should be educated on ways to mitigate risk of NIHL, including proper hearing protection (Parra et al., 2018), because the consequences of exposure to loud sound may emerge before clinically significant damage occurs.

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