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The Effect of Brief Subway Station Noise Exposure on Commuter Hearing

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Objective: To demonstrate that brief exposure to subway noise causes temporary threshold shift and is preventable with noise protection.

Methods: The study was conducted as a randomized crossover trial. Twenty subjects were randomly assigned to two groups, one with hearing protection and one without. Subjects were exposed to subway platform noise for 15 minutes. Pre- and post-exposure pure tone audiometry (PTA) and otoacoustic emissions were compared. After a washout period, subjects switched hearing protection groups and repeated the process.

Results: A statistically significant reduction in PTA thresholds after subway noise exposure was identified, for subjects with and without hearing protection ($P < .001$). For exposure without hearing protection, the mean threshold was 5.19 dB pre-exposure and 3.91 dB post-exposure (decrease of 1.28 dB; 95% confidence interval, 0.82–1.74). For exposure with hearing protection, the mean threshold was 4.81 dB pre-exposure and 3.47 dB post-exposure (decrease of 1.34 dB; 95% confidence interval, 0.89–1.79).

Conclusion: Brief exposure to subway noise did not cause hearing loss with or without noise protection. Though clinically insignificant, the unexpected finding of reduction in PTA suggests that there are complex heterogeneous short- and long-term cochlear responses to noise exposure that should be further explored.

Key Words: Subway noise, hearing loss, temporary threshold shift, noise exposure.
Level of Evidence: 1b

INTRODUCTION

In the United States alone, mass transit systems provide over 10.6 billion rides per year, with passenger rail making up nearly 47% of these rides.[1] In 2015, the underground rail systems, or subways, in Tokyo, Beijing, and Shanghai each topped 3 billion rides per year.[2] The New York City (NYC) subway is the seventh busiest worldwide and carries 5.7 million riders on an average weekday.[2]

Unfortunately, for all their utility, subways are notoriously noisy. In NYC, subway noise averages 80 to 90 A-weighted decibels (dBA) and reaches peaks of 104 to 121 dBA.[3–5] Prolonged exposure to this level of noise can surpass recommended exposure limits, clearly increasing risk for noise-inducted hearing loss (NIHL).[6,7] Importantly, even brief exposure to noises above 105 dBA, as experienced by commuters, raises concern for cochlear damage; recommended exposure limits for these levels are on the order of minutes.[3–7] Additionally, although the typical subway commute does fall within federal standards of allowable daily noise exposure (Table I), urban residents are exposed to a myriad of non-occupational noise sources on a daily basis.[3,6–8] Thus, the average noise exposure of subway commuters may exceed the recommended community limit of a yearly average of 70 dB per 24 hours, measured as an equivalent continuous sound level (L_{eq}).[9,10]

Excessive noise exposure risks not only NIHL with its typical notch at 3 to 4 kHz, but as Kujawa and Liberman's work has recently demonstrated that long before overt hearing loss, there is interruption of synaptic communication between hair cells and cochlear nerve leading to "hidden hearing loss" associated with a variety of perceptual abnormalities including speech-in-noise difficulties, tinnitus, and hyperacusis.[11,12] Effect of excessive noise is not limited to the inner ear alone, but can also lead to adverse medical and

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TABLE I.
Allowable Daily Exposure Durations for Given Noise Levels.[6,7]

	Exposure duration (min)					
	75 dBA	85 dBA	90 dBA	100 dBA	105 dBA	115 dBA
OSHA	No stated limit	960	480	120	60	15
NIOSH	No stated limit	480	151	15	4.7	<0.5

Modified from Gershon, et al.[4]
NIOSH = National Institute for Occupational Safety and Healthl; OSHA = Occupational Safety and Health Administration.

quality-of-life issues, such as hypertension, sleep disturbances, and social and occupational difficulties.[4,13,14]

The impact of subway noise on the hearing of daily commuters has yet to be studied. The effect on hearing loss incurred by chronic, repeated exposure to short periods of loud noise as exemplified by subway commuters remains uncertain.[4,15] Furthermore, because NIHL in cases of chronic exposure is gradual, commuters may not notice changes in hearing acuity and consequently may not feel compelled to wear hearing protection. Commuters may even unwittingly increase their noise exposure by listening to music at elevated volumes on personal devices during their commutes.[16,17]

Our overarching goal is to understand the long-term effects of chronic subway noise exposure on hearing. Previously, we have demonstrated that station design can impact commuter noise exposure: curved stations are much louder than straight stations.[3] In this study, we begin by investigating the impact on hearing of single short-term noise exposures on a subway platform. Specifically, we evaluate subjects for temporary threshold shift (TTS) following single short-term subway station noise exposure with and without hearing protection, using both pure tone audiometry (PTA) and distortion product otoacoustic emissions (DPOAEs). DPOAEs have been found to be more sensitive than PTA to early noise-induced change.[18] We have elected to expose subjects to subway platform noise as opposed to an actual subway ride, simulating a commuter waiting for the subway, to standardize noise exposure across subjects and to avoid unpredictable delays and variable trip durations for the same commute. Additionally, the noise levels on subway station platforms compared to subway car interiors have been shown to be louder.[5]

MATERIALS AND METHODS

Approval for this research was obtained from the Columbia University Institutional Review Board (Protocol IRB-AAAP4300).

Data Collection

The study was structured as a crossover trial simulating commuters' noise exposure on the subway platform while waiting for a train. Figure 1 illustrates the study format. Twenty fourth-year medical students at a single university were subjects for this study. This population was chosen to minimize the effect of variables such as age and noise exposure history, including baseline subway usage. Inclusion criteria were as follows: age of 18 years or older; no history of hearing loss or ear trauma; no history of otologic surgery; normal otoscopy; and baseline PTA thresholds less than or equal to 25 dB in both ears at 500, 1000, 2000, 3000, 4000, 6000, and 8000 Hz.

Subjects were randomized to one of two groups, each with 10 subjects (Table II). The noise exposure consisted of standing at the midpoint of a subway station platform (New York Subway 168th St Station, A/C train line, downtown platform) for 15 minutes. To attempt to standardize factors affecting station noise such as crowd size and number of trains passing through, all exposures took place at the same time of day (4:00 pm to 5:00 pm, weekday evenings). For the first exposure, subjects in Group 1 wore no hearing protection, while subjects in Group 2 wore earplugs with a 27 dB Noise Reduction Rating (Howard Leight AirSoft earplugs; Honeywell Safety Products, Smithfield, RI, USA). Earplugs were inserted or removed when subjects crossed the turnstile to enter or exit the station, respectively.

Before the noise exposure, baseline PTA was performed using the Hughson-Westlake method at 1 dB increments, for air conduction at octaves from 500 to 8000 Hz, as well as inter-octave frequencies of 3000 and 6000 Hz. Pre-exposure DPOAEs were also collected at 2000, 3000, 4000, 6000, and 8000 Hz, with these being the higher frequency (Frequency 2, or F_2). All audiologic evaluations for a given subject were performed by the same audiologist. After pre-exposure testing, subjects walked with a researcher to the marked midpoint of the subway platform for the noise exposure. Following the 15-minute subway noise exposure, subjects received post-exposure PTA and DPOAEs. Post-exposure testing was performed approximately 5 minutes after noise exposure because of travel time from the subway platform to the sound booth. If TTS greater than 15 dB was observed on the initial PTA, PTA was repeated at 30-minute intervals until thresholds were within 5 dB of baseline.

After post-exposure testing for the first exposure was completed, subjects underwent a 7-day washout period during which they did not use the subway and avoided other extremely noisy environments such as music clubs and concerts. Precisely 7 days after their first exposure, subjects crossed over to the other hearing protection group and repeated the process of pre-exposure testing, exposure, and post-exposure testing. Thus, for the second exposure, subjects originally in Group 1 used hearing protection, and subjects originally in Group 2 did not. Noise levels during the exposure periods were measured in dBA using a Brüel & Kjær 2250 Class I sound level meter (Brüel & Kjær Sound & Vibration Measurement A/S, Nærum, Denmark). Broadband L_{eq} (equivalent continuous sound level) was recorded.

Statistical Analysis

Pre-exposure and post-exposure PTA thresholds and DPOAEs were obtained for each subject in two conditions of noise exposure: 1) noise exposure with hearing protection and 2) noise exposure without hearing protection. Therefore, four sets of PTA thresholds and DPOAEs were obtained for each subject. These data were compared with the Repeated Measures ANOVA test. Effectiveness of the washout period was assessed by calculating the difference between subjects' thresholds from the first to the second pre-exposure test, then comparing the means for Group 1 and Group 2 using Student's t-test.

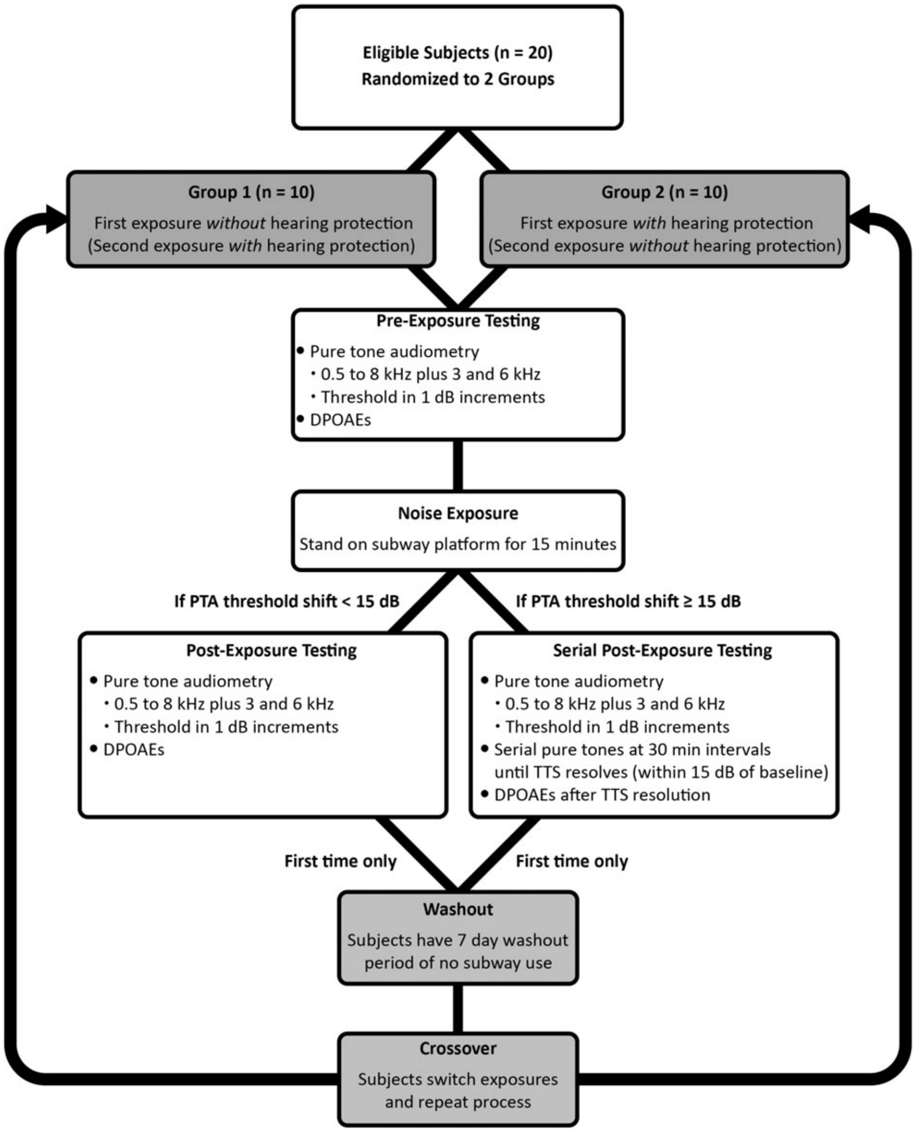

Fig. 1. *Flow chart of study format.* Twenty subjects were randomized into two exposure groups and underwent exposure and testing as illustrated.

TABLE II.
Characteristics of Subjects and Noise Exposures

Characteristic	Group 1 (n = 10)	Group 2 (n. = 10)
Mean Age ± SD (years)	26.2 ± 2.4	25.8 ± 0.9
Male sex	10 (50%)	10 (50%)
Exposure 1	No HP	HP
Mean noise level ± SD (dBA)	79.65 ± 0.79	79.61 ± 0.63
Range of noise level (dBA)	57.57 - 110.45	57.57 - 109.93
Mean time between exposure and post-exposure audiometry ± SD (minutes)	5.3 ± 0.8	5.1 ± 0.8
Exposure 2	HP	No HP
Mean noise level ± SD (dBA)	79.63 ± 0.83	79.48 ± 1.01
Range of noise level (dBA)	59.50 - 110.54	59.50 - 110.13
Mean time between exposure and post-exposure audiometry ± SD (minutes)	4.8 ± 0.8	5.3 ± 1.0

HP = hearing protection; SD = standard deviation.

RESULTS

Among the four sets of exposures, there were no significant differences in the time between exposure and post-exposure testing (P = .553), or in the average noise level on the platform (P = .983) (Table II). No subjects had TTS > 15 dB requiring repeat PTA.

Pure Tone Audiometry

Repeated measures ANOVA revealed a statistical trend of a decrease in PTA threshold after subway noise exposure (Fig. 2). When thresholds over all frequencies on both sides were analyzed together, a statistically significant reduction in PTA thresholds after subway noise exposure was observed, both with and without hearing protection ($P < .001$). For exposure without hearing protection, the mean threshold was 5.19 dB pre-exposure and 3.91 dB post-exposure (difference of 1.28 dB; 95% confidence interval (CI), 0.82–1.74). For exposure with hearing protection, the mean threshold was 4.81 dB pre-exposure and 3.47 dB post-exposure (difference of 1.34 dB; 95% CI, 0.89–1.79). No significant difference was observed between pre-exposure PTAs with or without hearing protection (difference of -0.38 dB; 95% CI, -0.99–0.22). Between Groups 1 and 2, there was no significant difference in the change in pre-exposure PTA from before to after crossing over (difference of -0.76 dB, P = .086), indicating a return to baseline thresholds after the 7-day washout period.

Distortion Product Otoacoustic Emissions

No change was seen in DPOAEs after exposure without hearing protection (mean difference, -0.57 dB; 95%

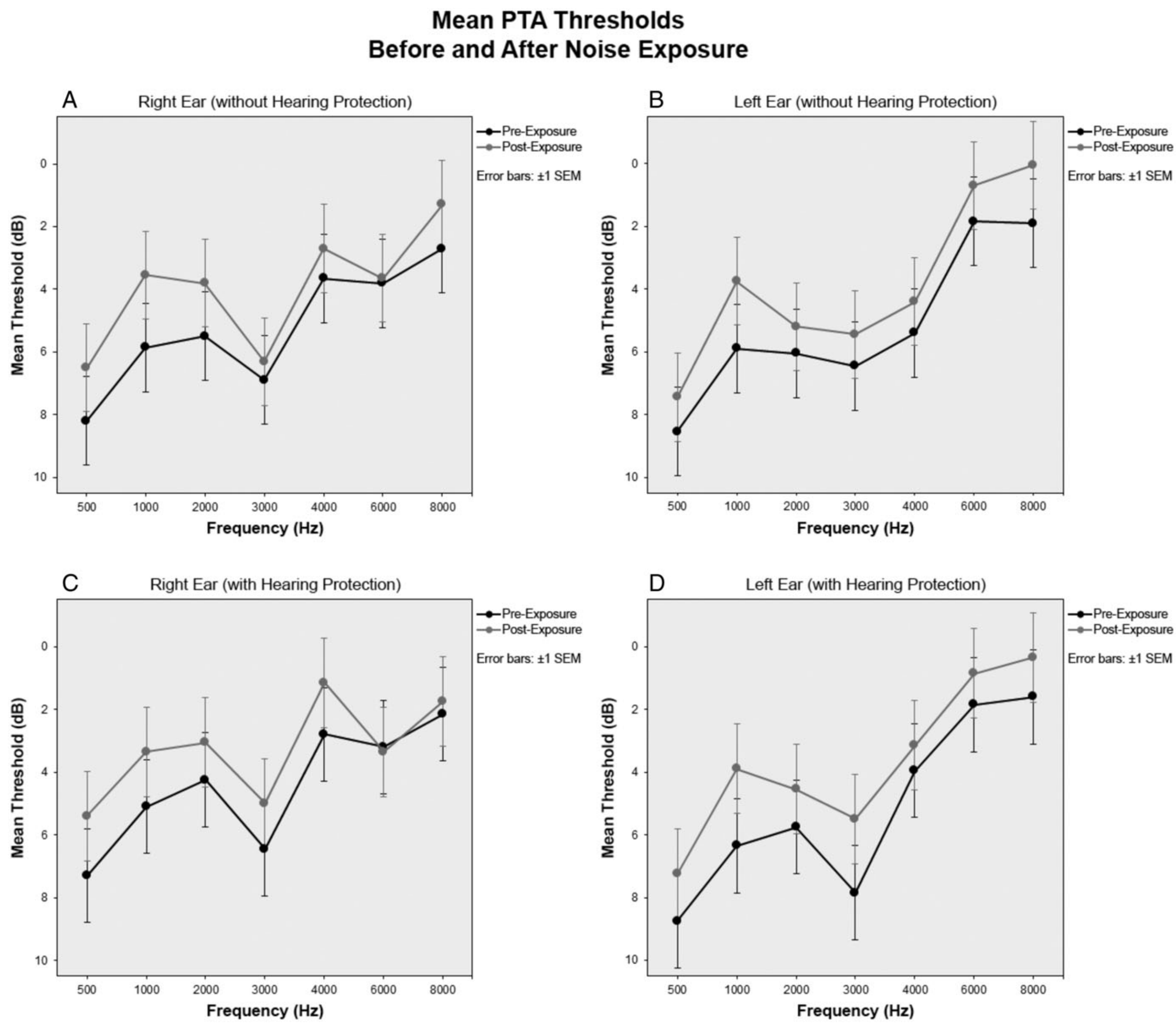

Fig. 2. *Mean PTA thresholds before and after noise exposure.* Thresholds trended on decreasing after subway noise exposure, regardless of whether hearing protection was worn. Panel A. Right ear without hearing protection. Panel B. Left ear without hearing protection. Panel C. Right ear with hearing protection. Panel D. Left ear with hearing protection.

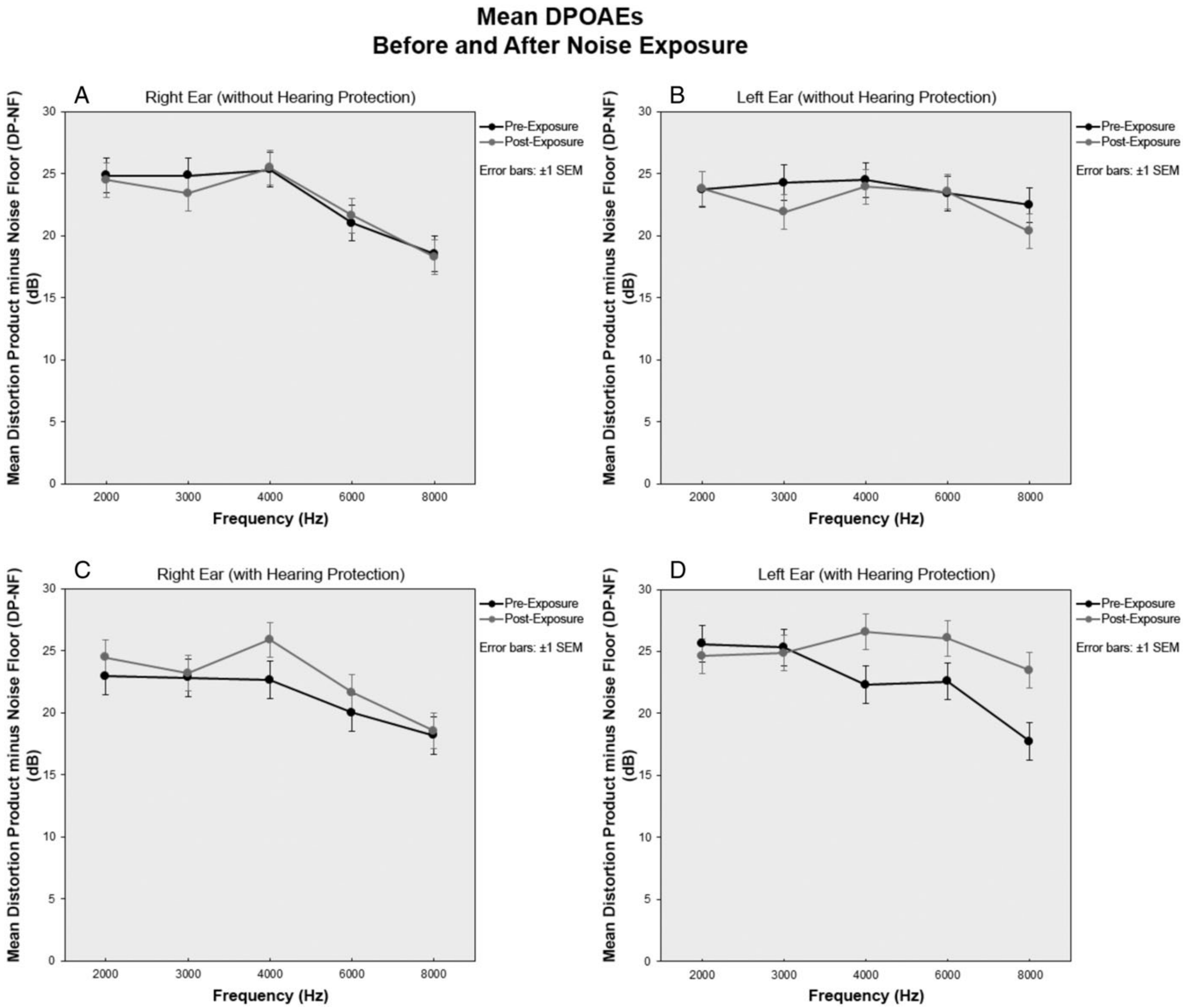

Fig. 3. *Mean DPOAEs before and after noise exposure.* Although no change was seen after exposure without hearing protection, an improvement in DPOAEs was seen after exposure with hearing protection. Panel A. Right ear without hearing protection. Panel B. Left ear without hearing protection. Panel C. Right ear with hearing protection. Panel D. Left ear with hearing protection.

CI, -1.76–0.62). However, an improvement in DPOAEs was seen after exposure with hearing protection (mean difference, 1.85 dB; 95% CI, 0.61–3.10) (Fig. 3). In contrast to PTA, there was a difference between the groups' DPOAE baseline changes from before to after crossing over. For subjects in Group 1, who did not wear hearing protection before their first exposure, the second set of pre-exposure DPOAEs averaged 0.13 dB higher than the first set. However, for Group 2 subjects, who wore hearing protection before their first exposure, the second set of pre-exposure DPOAEs averaged 2.46 dB higher than the first set (difference of 2.33 dB, P = .010).

DISCUSSION

Our study investigating the effects of New York City subway station noise on commuters' hearing demonstrated statistically significant reduction in PTA thresholds and elevated DPOAEs after 15 minutes of subway platform noise exposure with use of hearing protection. Additionally, there was a statistically significant reduction in PTA thresholds after noise exposure without hearing protection, but no similar elevation in DPOAE response. Though statistically significant, the difference is clinically *insignificant.* PTA thresholds returned to baseline one week after noise exposure regardless of whether hearing protection was used or not used. In contrast, DPOAEs remained elevated one week after noise exposure in subjects who wore hearing protection. This may represent a sensitization of hearing in response to increased ambient noise.[19–21]

In light of the average platform L_{eq} noise levels of 79.4 to 79.6 dB, it is not surprising that subjects did not experience temporary threshold elevation after subway noise exposure. However, the small but significant *reduction* in subjects' pure tone thresholds is notable as it is unexpected. Taken alone, this might reflect a learning effect as subjects better recognize the tones they are listening for after multiple audiometry sessions. However, the effect was seen after both exposures, and thresholds returned to baseline during the washout period instead of steadily improving through the second set of PTA exams. Furthermore, the increase in DPOAEs after subway noise exposure with hearing protection precludes the idea of a learning effect as the sole explanation, as it is a physiological metric with no active subject participation. It is more likely that the improvement in PTA and DPOAEs is due to hearing sensitization in response to noise. Our data suggests that, although the long term consequences of noise exposure are degenerative, the response to short term brief noise exposure is complex and heterogeneous, and warrants further investigation. Low-level noise has been shown to have a protective effect on both temporary and permanent noise-induced hearing loss.[19–21] As reflected by the improvement in OAEs, the mechanism of this effect is perhaps due to enzymatic changes in the cochlea, not simply middle ear muscle conditioning.[21,22] Olivocochlear efferent feedback, which decreases vulnerability to acute acoustic injury, may also play a role in the sensitization effect observed here, given that it manifested within minutes.[23–25]

The exposure in this study—by design—was a single exposure of short duration, restricted to the platform, and reflective of the noise spectrum in only one particular subway station. While it is reassuring that subjects did not experience temporary threshold elevation after a single noise exposure, it is difficult to generalize these findings to all commuters as their noise levels may be significantly higher. For example, a substantial proportion of subway riders use personal music devices, and are thereby clearly exposed to higher levels of noise than the subjects in this study, and are more likely to risk hearing damage. Longer commutes to and from major stations, which are often louder, would lead to more cumulative noise exposure and may carry higher risks of TTS or hidden hearing loss without the sensitization effect seen in this study.[4] Also, repeated exposure to these seemingly benign noise levels may lead to temporary or permanent threshold shifts not seen after a single exposure, and the diagnosis of NIHL in patients subjected to such noise could be missed because it appears more like age-related hearing loss.[26] A longitudinal study following a larger sample of actual commuters traveling various routes could provide clearer and more generalizable data. Alternatively, cross-sectional data of commuters who have used the subway regularly for different lengths of time would be valuable in assessing the effect of chronic exposure to short periods of subway noise. Clearly, the findings of our study highlights the importance of, and the need for, follow-up broader studies in the future.

CONCLUSION

In summary, a single brief exposure to subway platform noise did not cause hearing loss with or without hearing protection. Surprisingly, subjects exposed to subway noise demonstrated a small but statistically significant sensitization in hearing on pure tone audiometry and distortion product otoacoustic emissions after subway noise exposure. Additional studies are needed to assess the long-term auditory consequences of daily subway noise exposure. The very real risk of noise induced damage to hair cells, hidden hearing loss, and other adverse effects associated with excessive noise, warrants interventions to minimize commuter noise exposure.

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