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Original Article / *Özgün Makale*

Noise sensitivity and cochlear function in young adults: Insights from otoacoustic emission measures in high-volume headphone users

Gürültü hassasiyeti ve genç yetişkinlerde koklear işlev: Yüksek sesle kulaklık kullanan bireylerde otoakustik emisyon ölçümlerinden elde edilen veriler

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ABSTRACT

Objectives: This study aims to investigate the relationship between noise sensitivity and evoked otoacoustic emission (OAE) responses in individuals using headphones at high volume.

Patients and Methods: In this cross-sectional study, 36 normal-hearing participants (25 females, 11 males; mean age: 21.4±1.8 years; range, 18 to 35 years) completed the Weinstein Noise Sensitivity Scale (WNSS) and underwent transient evoked otoacoustic emissions (TEOAE) and distortion product otoacoustic emissions (DPOAE) testing at 1-5 kHz between May 27, 2025 and June 20, 2025. Correlations between age, WNSS scores, and OAE responses were analyzed. Participants were grouped by daily headphone use duration for between-group comparisons.

Results: No significant correlations were found between WNSS scores or age and OAE responses at any frequency. However, a significant reduction in the DPOAE response at 5 kHz was observed in individuals using headphones for 6 to 8 h per day (p=0.038).

Conclusion: While noise sensitivity was not associated with cochlear response patterns, extended exposure to high-volume headphone use may lead to early subclinical changes, particularly in high-frequency cochlear regions. Otoacoustic emission testing may be useful in identifying early auditory effects in at-risk populations.

Keywords: Cochlear outer hair cells, noise sensitivity, otoacoustic emissions.

ÖZ

Amaç: Bu çalışmada, yüksek sesle kulaklık kullanan bireylerde gürültü hassasiyeti ile uyarılmış otoakustik emisyon (OAE) yanıtları arasındaki ilişki araştırıldı.

Hastalar ve Yöntemler: Kesitsel çalışmada, 36 normal işiten birey (25 kadın, 11 erkek; ort. yaş: 21.4±1.8 yıl; dağılım, 18-35 yıl), 27.05.2025 - 20.06.2025 tarihleri arasında Weinstein Gürültü Hassasiyeti Ölçeğini (WGHÖ) tamamladı ve 1-5 kHz frekanslarında geçici uyarılmış otoakustik emisyonlar (TEOAE) ve bozulma ürünü otoakustik emisyonlar (DPOAE) testlerine tabi tutuldu. Yaş, WGHÖ puanı ve OAE yanıtları arasındaki korelasyonlar analiz edildi. Katılımcılar, gruplar arası karşılaştırmalar için günlük kulaklık kullanım süresine göre gruplandırıldı.

Bulgular: Weinstein Gürültü Hassasiyeti Ölçeği puanları veya yaş ile OAE yanıtları arasında hiçbir frekansta anlamlı bir ilişki bulunmadı. Ancak, günlük 6-8 saat kulaklık kullanan bireylerde 5 kHz'de DPOAE yanıtlarında anlamlı bir azalma gözlendi (p=0.038).

Sonuç: Gürültü hassasiyeti ile koklear yanıtlar arasında doğrudan bir ilişki saptanmamış olsa da, uzun süreli yüksek sesli kulaklık kullanımı, özellikle yüksek frekans bölgelerinde erken koklear değişikliklere yol açabilir. Otoakustik emisyon testi risk altındaki bireylerde erken işitsel etkilerin belirlenmesinde faydalı olabilir.

Anahtar sözcükler: Koklear dış tüy hücreleri, gürültü hassasiyeti, otoakustik emisyon.

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Noise is commonly defined as an unwanted or disturbing sound. However, the perception of noise is inherently subjective and varies significantly between individuals. This variability is often captured by the concept of noise sensitivity, which refers to a person's reactivity to noise, regardless of its intensity or duration. Individuals with high noise sensitivity may experience more discomfort and negative emotional responses even at lower sound levels, whereas others might remain unaffected under the same acoustic conditions.[1]

Over the past two decades, the widespread use of personal listening devices, such as headphones and earbuds, specifically among adolescents and young adults, has raised concerns about repeated exposure to high sound levels. This trend is particularly alarming considering that many users are unaware of safe listening practices and frequently exceed recommended volume limits. Prolonged exposure to high-intensity sound, even if intermittent, can result in subclinical damage to the cochlea, particularly the outer hair cells, which are critical for sound amplification and frequency discrimination.[2,3]

Otoacoustic emissions (OAEs), particularly transient evoked otoacoustic emissions (TEOAE) and distortion product otoacoustic emissions (DPOAE) responses, are sensitive and noninvasive tools for assessing cochlear outer hair cell function. These tests can detect early cochlear dysfunction even before changes are evident in the audiogram. Diminished OAE amplitudes are often considered early markers of cochlear stress or damage, particularly in noise-exposed populations.[4,5]

While the effects of noise exposure on cochlear function have been widely studied, the relationship between subjective noise sensitivity and objective cochlear health indicators remains unclear. Some studies suggest that noise sensitivity may correlate with physiological vulnerability to noise, while others argue that it is predominantly a psychological or personality-related trait.[6] Moreover, there is limited evidence exploring whether individuals with high noise sensitivity who also engage in risky listening behaviors, such as high-volume headphone use, may exhibit early cochlear alterations.

The current study aimed to explore this potential interaction by examining the relationship between noise sensitivity, as measured by the Turkish version of the Weinstein Noise Sensitivity Scale (WNSS), and OAE responses in young adults using headphones at high volume.[7] Additionally, the influence of age and duration of headphone use on OAE outcomes was evaluated. Understanding whether subjective sensitivity is reflected in objective auditory measures may provide insights into personalized preventive strategies and early risk identification.

PATIENTS AND METHODS

This cross-sectional observational study was conducted with 36 volunteers (25 females, 11 males; mean age: 21.39±1.80 years; range, 18 to 35 years) at the Gazi University Faculty of Health Sciences, Department of Audiology between May 27, 2025 and June 20, 2025. All participants reported listening at high volumes (operationally defined as >70% of device output or self-reported "loud" settings). Although sound pressure levels were not directly measured with a sound level meter in this study, previous literature indicates that such levels typically range from approximately 85 to 95 dB SPL, which may exceed daily occupational noise exposure limits when listening duration is prolonged. Inclusion criteria were as follows: normal hearing thresholds (<25 dB hearing loss at 250 to 8000 Hz), absence of hearing complaints, and the mental and physical ability to complete the study. Individuals with a history of otologic disease, diagnosed hearing loss, or noise exposure from occupational sources were excluded. All participants provided written informed consent before enrollment. The study protocol was approved by the Gazi University Ethics Committee (Date: 27.05.2025, No: 2025/537). The study was conducted in accordance with the principles of the Declaration of Helsinki.

The study was conducted in three stages: *(i)* demographic and behavioral data collection; *(ii)* assessment of noise sensitivity; *(iii)* evoked otoacoustic emission testing.

In the first stage, participants completed an online questionnaire collecting demographic information (age and sex) and headphone use habits (daily usage duration, preferred volume level, and years of use). Headphone use duration was categorized into 0-2 h, 2-4 h, 4-6 h, and 6-8 h per day. In the second stage, noise sensitivity was evaluated using the Turkish adaptation of the WNSS.[7] This self-report scale consists of 21 items rated on a 6-point Likert scale (1=strongly disagree, 6=strongly agree). Total scores range from 21 to 126, with higher scores indicating greater sensitivity. The validated Turkish version was used with permission. In the third stage, TEOAE and DPOAE responses were recorded in a sound-treated booth using a calibrated otoacoustic emission system

Table 1
Correlation between age and noise sensitivity with OAE responses

	Age			WNSS		
Frequency	r	95% CI	*p*	r	95% CI	*p*
1 kHz TEOAE	0.079	−0.181-0.360	0.648	−0.120	−0.496-0.270	0.487
2 kHz TEOAE	−0.003	−0.359-0.346	0.988	−0.074	−0.387-0.283	0.669
3 kHz TEOAE	−0.234	−0.482-0.053	0.169	0.066	−0.311-0.448	0.702
4 kHz TEOAE	−0.064	−0.379-0.270	0.713	0.059	−0.307-0.402	0.731
5 kHz TEOAE	0.023	−0.297-0.331	0.898	−0.201	−0.533-0.168	0.247
1 kHz DPOAE	0.029	−0.319-0.383	0.865	−0.146	−0.462-0.212	0.394
2 kHz DPOAE	0.113	−0.234-0.451	0.513	0.089	−0.248-0.418	0.605
3 kHz DPOAE	0.087	−0.265-0.449	0.613	−0.076	−0.410-0.280	0.661
4 kHz DPOAE	0.018	−0.345-0.370	0.917	0.023	−0.331-0.371	0.894
5 kHz DPOAE	0.186	−0.192-0.505	0.277	−0.055	−0.364-0.272	0.748

OAE: Otoacoustic emission; CI: Confidence interval; WNSS: Weinstein Noise Sensitivity Scale; TEOAE: Transient Evoked Otoacoustic Emission; DPOAE: Distortion Product Otoacoustic Emission; Spearman correlation coefficients (r) and corresponding p-values were shown.

(Neuro-Audio; Neurosoft, Ivanovo, Russia). For TEOAE, 80 dB pe SPL clicks were presented with a repetition rate of 50 Hz. A signal-to-noise ratio ≥6 dB was required for response validity.

For DPOAE, primary tones f1 and f2 were presented with a frequency ratio of f2/f1=1.22 and levels of L1=65 dB SPL and L2=55 dB SPL. The DPOAEs were recorded at 1, 2, 3, 4, and 5 kHz. All measurements were performed bilaterally, and the better-ear responses were used in analysis.

Statistical analysis

Instead of doing an a priori power analysis, the sample size was pragmatically selected by looking at the pool of volunteers who were available. The acquired sample (n=36) permitted preliminary statistical inference, with 95% confidence intervals presented with descriptive data, despite the lack of a formal sample size calculation. Data were analyzed using IBM SPSS version 25.0 software (IBM Corp., Armonk, NY, USA). Normality was assessed with the Shapiro-Wilk test. Due to nonnormal distribution, nonparametric tests were employed. Spearman's rank correlation was used to evaluate the association between WNSS scores, age, and OAE amplitudes across frequencies. The Kruskal-Wallis test was used to compare OAE amplitudes across headphone use duration groups. A p-value <0.05 was considered statistically significant.

RESULTS

All participants had normal hearing thresholds and reported using headphones at high volume levels regularly. The mean noise sensitivity score, as measured by the WNSS, was 90.94±14.22; range, 61 to 116).

Spearman's rank correlation analysis was performed to examine the associations between participants' age and WNSS scores with OAE responses. No statistically significant correlations were observed between age and either TEOAE or DPOAE amplitudes at any frequency tested (p>0.05 for all; Table 1). Similarly, WNSS scores did not show significant correlations with OAE amplitudes across any frequency (p>0.05), indicating that neither age nor subjective noise sensitivity were associated with outer hair cell function as measured by evoked OAEs in this sample.

Participants were categorized into four groups based on their mean daily headphone use duration: 0-2 h (n=14), 2-4 h (n=9), 4-6 h (n=9), and 6-8 h (n=4). The OAE amplitudes were compared between these groups using the Kruskal-Wallis test. No statistically significant differences were found across usage groups for either TEOAE or DPOAE responses at 1, 2, 3, or 4 kHz (p>0.05). However, a significant difference was observed at 5 kHz in DPOAE amplitudes (p=0.038), where the 6 to 8 h group exhibited reduced responses compared to other usage durations (Table 2).

DISCUSSION

This study aimed to investigate the relationship between noise sensitivity and evoked OAE responses in individuals using headphones at high volumes.

Table 2
Comparison of TEOAE and DPOAE responses by headphone use duration

	0-2 h	0-2 h	0-2 h	2-4 h	2-4 h	2-4 h	4-6 h	4-6 h	4-6 h	6-8 h	6-8 h	6-8 h	
Frequency	Median	Range	95% CI	Median	Range	95% CI	Median	Range	95% CI	Median	Range	95% CI	*p*
1 kHz TEOAE	6.05	0.00-21.00	4.18-11.30	7.90	6.10-14.00	6.55-10.25	7.00	1.10-13.00	4.87-10.50	5.00	3.00-6.70	2.13-7.72	0.262
2 kHz TEOAE	11.00	6.10-14.00	9.05-11.85	10.00	6.40-13.00	8.08-11.60	9.90	6.60-13.00	7.80-11.69	7.10	6.10-10.00	4.85-10.30	0.239
3 kHz TEOAE	6.55	1.00-16.00	5.93-10.22	6.10	3.10-9.20	5.21-7.74	6.50	4.70-12.00	5.39-8.50	6.35	5.40-12.00	2.72-12.33	0.704
4 kHz TEOAE	5.40	–4.90-6.70	1.31-5.64	3.10	–8.90-6.10	–4.18-4.35	1.40	–4.00-6.00	–0.72-4.09	3.85	0.30-9.50	–2.35-11.10	0.236
5 kHz TEOAE	-2.20	–11.00-3.90	–4.76–-0.49	0.00	–7.50-2.50	–4.71-0.89	–1.90	–12.00-5.00	–7.34-0.48	2.55	–2.90-6.70	–4.58-9.03	0.151
1 kHz DPOAE	7.05	3.00-18.00	5.91-11.14	8.20	0.00-18.00	5.16-13.68	9.30	0.00-14.00	4.06-11.47	6.60	5.00-9.30	4.01-9.74	0.779
2 kHz DPOAE	9.65	6.00-18.00	8.44-12.03	9.40	–2.40-13.00	5.16-12.50	11.00	–14.00-13.00	1.21-14.01	6.65	4.20-7.30	3.98-8.42	0.128
3 kHz DPOAE	6.30	5.00-11.00	5.97-7.92	6.20	0.00-15.00	3.89-10.37	6.20	0.00-12.00	3.49-9.42	8.20	0.00-12.00	–1.25-15.45	0.872
4 kHz DPOAE	4.75	–2.50-13.00	2.51-6.69	4.60	–11.00-6.10	–1.81-6.43	4.30	–8.60-11.00	–2.59-6.92	6.75	0.50-12.00	–1.00-14.00	0.292
5 kHz DPOAE	-3.90	–16.00-1.00	–7.69–-2.43	-1.90	-18.00–-0.60	–8.33-0.04	–1.30	–9.30-6.30	–5.16-2.20	1.05	–2.10-4.10	–3.23-5.28	0.038

TEOAE: Transient Evoked Otoacoustic Emission, DPOAE: Distortion Product Otoacoustic Emission; CI: Confidence interval. Statistical comparisons were performed using Kruskal-Wallis test. * p<0.05 indicates statistical significance.

While no significant associations were found between noise sensitivity scores and OAE amplitudes, a significant reduction in DPOAE responses at 5 kHz was observed in individuals who used headphones for extended durations daily. These findings contribute to the understanding of how subjective noise perception and objective cochlear function may interact in the context of modern listening habits.

Our analysis showed that noise sensitivity, as measured by the WNSS, was not significantly associated with TEOAE or DPOAE amplitudes. This is consistent with prior research indicating that noise sensitivity is primarily a psychological trait rather than a marker of peripheral auditory dysfunction.[8] The Turkish validation study of the WNSS also found no significant difference in TEOAE amplitudes between noise-sensitive and nonsensitive individuals, despite notable variability in questionnaire scores.[1,7] These results reinforce the notion that noise sensitivity does not necessarily reflect cochlear vulnerability, at least among individuals with clinically normal hearing thresholds.

Interestingly, our findings did reveal a significant reduction in DPOAE amplitudes at 5 kHz in participants who reported using headphones for 6 to 8 h per day. High-frequency regions of the cochlea, particularly those responsible for encoding 4 to 8 kHz sounds, are known to be more susceptible to early noise-induced damage.[3,5] The DPOAE reduction at 5 kHz may represent a subclinical sign of outer hair cell dysfunction that precedes audiometric threshold shifts and supports concerns about prolonged, high-volume headphone use. Given that DPOAE is more sensitive to frequency-specific cochlear changes, particularly at higher frequencies, this finding aligns with previous reports on early markers of noise-induced hearing risk.

The absence of a significant correlation between age and OAE responses is expected, considering the narrow and relatively young age range (18 to 35 years) of the sample. Previous research has shown that aging effects on OAE responses typically become prominent in individuals over the age of 40.[8] Thus, the age-related component is unlikely to be a contributing factor in the present cohort.

From a clinical perspective, our results underscore the importance of monitoring high-risk listening behaviors, such as extended daily headphone use, even in the absence of subjective complaints or measurable hearing loss. The early changes observed at 5 kHz may provide a valuable biomarker for preventive audiology, particularly for young adults

engaged in leisure noise exposure. Additionally, public health strategies should incorporate education on safe listening practices and promote regular hearing check-ups that include OAE assessments in noise-exposed populations.

Nevertheless, this study had several limitations. First, the sample size was relatively small, particularly in the subgroup of participants using headphones for more than 6 h per day, which may have limited the statistical power to detect more subtle associations. Second, the study relied on self-reported headphone use duration, which may be subject to recall bias and does not account for actual sound pressure levels or type of earphones used. Third, the cross-sectional design prevents any conclusions about causality between headphone use and cochlear function. Additionally, although the WNSS provides a validated subjective measure, it may not fully capture the complexity of central auditory processing mechanisms involved in noise sensitivity. Future studies should aim to include larger and more diverse populations, integrate objective measurements of daily noise exposure (e.g., dosimetry), and use longitudinal designs to track changes in OAE over time. Furthermore, exploring central auditory processing tests or electrophysiological measures alongside OAE could provide deeper insights into the mechanisms linking noise sensitivity and auditory system vulnerability in noise-exposed individuals.

In conclusion, this study investigated the association between noise sensitivity and evoked otoacoustic emission responses in young adults who regularly use headphones at high volume. The results indicate that subjective noise sensitivity was not significantly associated with cochlear outer hair cell function, as measured by TEOAE and DPOAE. However, a significant reduction in DPOAE amplitudes at 5 kHz was observed among individuals with longer daily headphone use, suggesting early high-frequency cochlear vulnerability due to prolonged noise exposure. These findings highlight the importance of preventive hearing health strategies, particularly among young populations with recreational noise habits. While noise sensitivity may not directly reflect cochlear pathology, extended high-volume headphone use could result in subtle cochlear dysfunction that is detectable before audiometric threshold shifts occur. Routine otoacoustic emission testing and education on safe listening practices should be considered as part of early intervention efforts. Future studies should include larger and more diverse samples, incorporate objective measures of sound exposure, and explore longitudinal changes in OAE responses to better understand the progression of noise-related auditory risks.

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