ORIGINAL ARTICLE

Short-term Auditory Effects of Listening to an MP3 Player

Hannah Keppler, MS; Ingeborg Dhooge, MD, PhD; Leen Maes, MS; Wendy D'haenens, MS; Annelies Bockstael, MS; Birgit Philips, MS; Freya Swinnen, MS; Bart Vinck, MS, PhD

Objectives: To determine the output levels of a commercially available MPEG layer-3 (MP3) player and to evaluate changes in hearing after 1 hour of listening to the MP3 player.

Design: First, A-weighted sound pressure levels (measured in decibels [dBA]) for 1 hour of pop-rock music on an MP3 player were measured on a head and torso simulator. Second, after participants listened to 1 hour of pop-rock music using an MP3 player, changes in hearing were evaluated with pure-tone audiometry, transient-evoked otoacoustic emissions, and distortion product otoacoustic emissions.

Participants: Twenty-one participants were exposed to pop-rock music in 6 different sessions using 2 types of headphones at multiple preset gain settings of the MP3 player.

Main Outcome Measures: Output levels of an MP3 player and temporary threshold and emission shifts after 1 hour of listening.

Results: The output levels at the full gain setting were 97.36 dBA and 102.56 dBA for the supra-aural headphones and stock earbuds, respectively. In the noise exposure group, significant changes in hearing thresholds and transient-evoked otoacoustic emission amplitudes were found between preexposure and postexposure measurements. However, this pattern was not seen for distortion product otoacoustic emission amplitudes. Significant differences in the incidence of significant threshold or emission shifts were observed between almost every session of the noise exposure group compared with the control group.

Conclusions: Temporary changes in hearing sensitivity measured by audiometry and otoacoustic emissions indicate the potential harmful effects of listening to an MP3 player. Further research is needed to evaluate the long-term risk of cumulative noise exposure on the auditory system of adolescents and adults.

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Author Affiliations: Ear, Nose, and Throat Department, Faculty of Medicine and Health Sciences, Ghent University, Ghent, Belgium.

It is well known that excessive occupational noise exposure can lead to noise-induced hearing loss (NIHL). Furthermore, the impact of recreational noise exposure on the auditory system is a cause for concern. This recreational noise exposure includes exposure to loud music or even participation in nonmusical activities (eg, practice of noisy sports). In the mainstream media, an increase in prevalence of NIHL owing to recreational noise exposure is assumed. The Third National Health and Nutrition Examination Survey, performed between 1988 and 1994, estimated a 12.5% prevalence of a noise-induced threshold shift in at least 1 ear of 6- to 19-year-old US children.[1] Recently, however, no increasing prevalence of hearing loss among US young adults (age, 17-25 years) was reported for hearing tests performed between 1985 and 2004.[2] This lack of hearing deterioration is most likely explained by the fact that recreational noise exposure is insufficient to cause widespread hearing loss. It is possible that recreational noise exposure occurs only for a small period in life, probably between 5 and 10 years.[3] Moreover, a greater public awareness of the potential harmful effects of recreational noise exposure might have increased the use of hearing protection and/or induced an alteration in noise exposure habits. It is also possible that it is too soon to detect the permanent effects of recent advances in personal music player (PMP) technology.

The technical evolution, from the introduction of the Sony Walkman to the MPEG layer-3 (MP3) player, has contributed to the current popularity of PMPs. There has been not only a miniaturization of the devices but also an improvement in storage and battery capacity as well

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as online availability of music and podcasts. Theoretically, PMP users are potentially at risk for NIHL because maximum output levels of digital music systems are reported to range from 100.0 to 110.5 A-weighted sound pressure levels (SPLs) (measured in decibels [dBA])[4] or from 101 to 107 dBA[5] using real ear measurements or a head and torso simulator (HATS), respectively. Moreover, it was found that the maximum output levels were a mean of 5 dB higher than those for portable CD players.[5] However, the estimation of risk criteria should be based on user-preferred listening levels and duration of exposure. Risk assessment ranges from 0.065% to 30%.[6-11] The variability could be explained by the definition for NIHL and the damage-risk criteria for hearing loss, which are directly adopted from occupational settings. Epidemiologic research revealed significant poorer hearing thresholds caused by listening to PMPs for more than 7 h/wk compared with those using PMPs for 2 to 7 h/wk or the controls.[12] Also, a decline in click-evoked otoacoustic emissions was significantly correlated with a history of PMP use.[13] Others found no significant hearing deterioration caused by PMPs,[14] and, moreover, PMPs were considered less risky to hearing than nightclubs or discotheques.[15,16] Nevertheless, there seems to be a general consensus that PMPs are potentially hazardous for hearing.

Excessive noise exposure can lead to metabolic and/or mechanical effects resulting in alterations of the structural elements of the organ of Corti.[17] The primary damage is concentrated on the outer hair cells, which are more vulnerable to acoustic overstimulation than inner hair cells.[18] Otoacoustic emissions (OAEs) are thought to reflect the nonlinear active processes of the cochlea based on the motile activity of the outer hair cells. Therefore, an amplitude reduction or loss of OAEs may reflect outer hair cell damage due to noise exposure.[19] The OAEs can be used to assess existing subclinical outer hair cell change and preclinical frequency-specific hearing loss.[20] Additional research regarding the usefulness of OAEs to detect minimal cochlear damage after loud music exposure is needed on a short-term as well as on a long-term basis.

The purpose of the present study was to measure the A-weighted equivalent SPLs of a commercially available MP3 player on a HATS using 2 different headphone styles at various preset gain settings. Furthermore, the short-term effects on the auditory system of young adults listening to the MP3 player for 1 hour were evaluated.

METHODS

OUTPUT MEASUREMENTS

Recording Equipment, MP3 Player, Headphones, and Music

Output measurements were conducted in a quiet room with the right ear simulator (Type 4158c) of a HATS Type 4128c (Brüel & Kjær, Nærum, Denmark). The microphone's response was registered using a Modular Precision Sound Analyzer Type 2260 Investigator (Brüel & Kjær) set at fast exponential time weighting. Calibration of the ear simulator was performed daily with a pistonphone Type 4228. Both the overall equivalent continuous A-weighted SPL ($L_{Aeq,T}$) and the 1/3-octave band level (dBA) between 0.2 and 10.0 kHz were of interest.

An iPod Nano 2 GB MP3 player (model A1199, second generation; Apple Inc, Cupertino, California) was bought for measurement purposes only, and the battery of the iPod was fully charged each time. The volume bar on the display was marked carefully to ensure reproducible measurements at gain settings 50% to 100% of the volume bar with a 5% step size. Two different types of headphones were coupled to the pinna of the HATS: the stock iPod earbuds (Apple Inc) and supra-aural OMX 52 Street Clip-on headphones (Sennheiser Inc, Wedemark-Wennebostel, Germany). According to the manufacturers, the frequency ranged from 0.02 to 20 kHz for the earbuds and from 0.017 to 21 kHz for the supra-aural headphones. The impedance of both earphone types was 32 Ω.

The music sample consisted of 17 songs from the CD *Afrekening Volume 37* (PIAS, Brussels, Belgium), which is a compilation CD from the hit lists of a popular Flemish radio station. The genre of the CD can be described as pop-rock, and all participants enjoyed listening to this music compilation. In **Table 1**, the artist name, song title, and duration of each track are provided. The compilation lasted exactly 1 hour, 1 minute, and 55 seconds, or 3715 seconds (reported from here on as 1 hour). The iTunes software (Apple Inc) was used to convert the tracks into an MP3 format at a bit rate of 160 kB/s.

Data Analysis

The measurements were analyzed using Noise Explorer Type 7815 software, version 4.5 (Brüel & Kjær) and exported to Excel spreadsheets (Microsoft Inc, Redmond, Washington). The $L_{Aeq,T}$ was calculated where T represents 1 hour for the whole CD and Tt, the duration of a track. Although the effect of noise on the auditory system of humans is more accurately described using the SPL at the eardrum, free-field–related SPLs normalized to 8 hours are commonly used for comparing the data with criteria stipulated in the European Directive 2003/10/EC regarding noise exposure of workers.[21] Therefore, the $L_{Aeq,8h}$ of 1 hour of music exposure through an MP3 player was calculated as $L_{Aeq,8h}=L_{Aeq,Te} + 10 \log_{10}(T_e/T_o)$, where T_e is the actual exposure (1 hour) and T_o is the reference duration (8 hours). Moreover, the at-ear SPL was converted to the free-field–related SPL by means of a head-related transfer function, which includes the effects of the head, torso, pinna, ear canal, and ear simulator. Hammershoi and Moller[22] derived standard free-field-front head-related transfer function data at 1/3-octave frequency bands, which are used in the present study.

HEARING MEASUREMENTS

Participants

First, the noise exposure group listening to pop-rock music for 1 hour included 10 men and 11 women aged 19 to 28 years. Second, the control group included 14 men and 14 women, also ranging in age from 19 to 28 years. All voluntarily participated in the study, which was approved by the local ethical committee, and gave their informed consent in accordance with the Declaration of Helsinki. Participants were enrolled in the study if they had no recent history of ear disease and no noise or music exposure during the past 48 hours. Furthermore, normal otoscopic examination was necessary, and only ears with type-A tympanogram, measured with an 85-dB SPL probe tone at 226 Hz, and a normal ipsilateral acoustic reflex threshold at 1000 Hz were included (TympStar; Grason-Stadler Inc, Eden Prairie, Minnesota).

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Table 1. Artist, Song Title, Track Duration, and Noise Exposure per Track at Gain Setting 100% of the iPod Nano

Track	Artist	Song Title	Track Duration, min:s	$L_{Aeq,T}$, dBA	
				Earbuds	Supra-aural Headphones
1	Weezer	"Beverly Hills"	03:20	101.10	95.06
2	Skitsoy	"Disconnect"	04:32	101.07	95.01
3	Beck	"E-Pro"	03:20	100.98	97.18
4	Millionaire	"For a Maid"	03:25	104.56	99.06
5	Funeral Dress	"Freedom & Liberty"	03:16	103.47	98.74
6	Eels	"Hey Man"	03:00	100.42	93.81
7	Queens of the Stone Age	"In My Head"	04:01	103.75	98.27
8	Janez Detd.	"Killing Me"	03:16	101.18	95.75
9	Admiral Freebee	"Lucky One"	04:11	103.56	98.04
10	Oasis	"Lyla"	05:12	104.53	99.56
11	't Hof Van Commerce	"Niemand Grodder"	03:39	100.43	94.25
12	Sum41	"Pieces"	03:01	103.36	98.86
13	Garbage	"Run Baby Run"	03:59	103.50	99.40
14	Bloc Party	"So Here We Are"	03:16	103.27	98.64
15	Dropkick Murphys	"Sunshine Highway"	03:23	104.24	98.18
16	Gabriel Rios	"Unrock"	03:33	95.24	88.74
17	Jeugd Van Tegenwoordig	"Watskeburt?!"	03:31	98.32	92.28
Total	. . .	. . .	61:55	102.56	97.36

Abbreviations: dBA, A-weighted decibels; ellipses, not applicable; $L_{Aeq,T}$, equivalent continuous A-weighted sound pressure level for the duration specified.

Table 2. Free-Field Corrected 1-Hour and 8-Hour Equivalent Continuous A-Weighted Noise Exposure Level

	Noise Exposure Group, Session No.								Control Group (n=28)
	(n=21)				(n=15)				
	1	2	3	4	5		6		1
Headphone style	Earbuds	Supra-aural headphones	Earbuds	Supra-aural headphones	Earbuds		Supra-aural headphones		. . .
Gain setting, %	50	50	75	75	>75		>75		. . .
					90	100	90	100	. . .
L_{Aeq}, 1 h, dBA	70.21	60.64	83.26	73.34	92.41	96.46	81.12	86.14	. . .
L_{Aeq}, 8 h, dBA	61.18	51.61	74.23	64.31	83.38	87.43	72.09	77.11	. . .
No. of ears									
Men	10	10	10	10	7		7		14
Women	11	11	11	11	8		8		14

Abbreviations: dBA, A-weighted decibels; ellipses, not applicable (no noise exposure); L_{Aeq}, equivalent continuous A-weighted sound pressure level.

Experimental Design

A maximum of 6 sessions of listening to an iPod Nano MP3 player were completed by the noise exposure group with at least 48 hours between 2 successive sessions. To reduce variability in listening levels, 4 sessions were conducted at preset gain setting 50% or 75% with the stock iPod earbuds or supra-aural Sennheiser headphones. Then, 2 additional sessions with both headphone styles were conducted at a gain setting of more than 75%, which was individually determined and defined by the participant as a loud but comfortable setting. Six participants did not listen to music at a gain setting higher than 75% because these higher gain settings were no longer comfortable for them. The remaining 15 participants listened at gain setting 90% (1 man and 2 women) or 100% (6 men and 6 women). Hearing status was evaluated before and after 1 hour in both groups by pure-tone audiometry, transient-evoked OAEs (TEOAEs), and distortion product OAEs (DPOAEs). All hearing tests were conducted in a double-walled sound-attenuated booth. Only 1 ear per participant was tested at random to obtain an equal number of left and right ears per sex. Because the number of participants was too small to account for the effect of test order, a fixed order was used. The TEOAEs were conducted first, followed by DPOAEs and pure-tone audiometry. After the listening session, hearing tests were immediately performed, and it was possible to keep the test duration within 10 minutes. The design of the study is summarized in **Table 2**.

Pure-tone air conduction thresholds were obtained using the standard clinical modified Hughson-Westlake method with a 5-dB step size at octave frequencies from 0.25 through 8.0 kHz in complement with half-octave frequencies 3.0 and 6.0 kHz (Orbiter 922 Clinical Audiometer with TDH-39 headphones; Madsen Electronics, Taastrup, Denmark). All participants had normal hearing during the preexposure measurements; ie, hearing thresholds equal to or better than 25-dB hearing level at all tested frequencies. An ILO (Institute of Laryngology and Otology) 288 USB II module (Otodynamics Ltd, Herts, England) in complement with the ILO software, version 6, and DPOAE probe was used for both OAE measurements. Probe calibration was performed at the beginning of each session using the 1-cm^3 calibra-

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tion cavity provided by the manufacturer. First, for TEOAEs, the nonlinear differential method of stimulation with rectangular pulses of 80 μs at a rate of 50 clicks per second was applied. Clicks were evoked with an intensity of 80 ± 3-dB peak SPL, and registration was stopped after 260 accepted sweeps. The noise rejection setting was set at 4 mPa (46.0-dB SPL). The emission and noise amplitudes at half-octave frequency bands with center frequencies 1.0, 1.4, 2.0, 2.8, and 4.0 kHz were calculated by the ILO software. The TEOAEs were considered present if the emission amplitude relative to the noise floor (signal to noise ratio) within each corresponding half-octave frequency band was greater than 0 dB. When the criterion was not met at preexposure measurements, the emission and noise amplitudes were treated as missing data. Across half-octave frequency bands, 1.55% of the data points were treated as missing data. In some cases, TEOAEs could be considered present at preexposure measurements but were below the noise floor at postexposure measurements. To ensure use of more data, the postexposure emission amplitudes were substituted for the postexposure noise floor if this noise floor was smaller than the preexposure emission amplitude. When the postexposure noise floor exceeded the preexposure emission amplitude, the preexposure and postexposure measurement emission and noise amplitudes were considered to be missing data. This substitution was limited so that detectable changes were not the consequence of fluctuations in the noise floor. This resulted in 1.38% of the additional data points being treated as missing data and 1.03% substitutions. Second, DPOAEs were evoked using 2 primary frequencies, f1 and f2, with f2/f1 = 1.22 and primary frequency f2 ranging from 0.842 to 7.996 kHz. Primary tone level combination L1/L2 = 75/70-dB SPL was used to ensure an optimal signal to noise ratio and reduce the amount of missing data. Furthermore, a noise artifact rejection level of 4 mPa (46.0-dB SPL) was applied. The emission and noise amplitudes were averaged into half-octave frequency bands, where f2 ranged from 0.842 to 1.189 kHz, 1.297 to 1.542 kHz, 1.682 to 2.181 kHz, 2.378 to 3.084 kHz, 3.364 to 4.362 kHz, 4.757 to 6.727 kHz, and 7.336 to 7.996 kHz, respectively, for half-octave frequency bands with center frequencies 1.0, 1.4, 2.0, 2.8, 4.0, 6.0, and 8.0 kHz. The DPOAEs were considered present if the emission amplitude was larger than the noise level (signal to noise ratio >0 dB) within each corresponding frequency region. When this criterion was not met at a particular frequency, emission and noise amplitudes were treated as missing data for the preexposure and postexposure measurements. In total, 3.52% of the data points across frequencies were considered to be missing data. The TEOAE and DPOAE data analysis techniques have been described elsewhere.[23]

Data Analysis

Statistical analysis was performed using SPSS statistical software, version 15 (SPSS Inc, Chicago, Illinois). Three-way repeated-measures analysis of variance with measurement (preexposure vs postexposure), gain setting (50%, 75%, and >75%), and type of headphones (earbuds vs supra-aural headphones) was conducted to evaluate the changes in audiometric thresholds or OAE amplitudes. When the significance level was reached ($P < .05$), post hoc least significant difference (LSD) test with Bonferroni correction was executed between the conditions of interest (ie, preexposure and postexposure measurements). Second, the recovery of hearing thresholds or OAE amplitudes between the first and each subsequent preexposure measurement was analyzed by 1-way analysis of variance using $P < .05$ and a post hoc LSD test. Third, based on the standard error of measurement (SEM) from the control group, significant threshold shifts (STSs) for pure-tone audiometry as well as significant emissions shifts (SESs) were derived. The SEM estimates the magnitude of significant changes within a subject. It is calculated as $SEM = s\sqrt{(1 - ICC)}$, where s represents the standard deviation of all measurements and ICC is the 2-way random intraclass correlation coefficient between the preexposure and postexposure measurements. The 95% confidence interval of the minimal detectable difference was calculated as $1.96\sqrt{2}SEM$ and can be considered a real change in a participant's score above measurement error. The minimal detectable difference was rounded up to the next step size: 5-dB hearing level for pure-tone audiometry and 0.1-dB SPL for OAEs. The percentage of significant shifts was determined in the control group, as well as in each session of the noise exposure group. Missing data reduced the valid number of cases for the calculation of the percentage to at least 26 and 14 ears for the control and noise exposure groups, respectively. These missing data were caused by the data-cleaning process and the absence of data from 6 individuals who did not listen at gain settings above 75%. Because the preexposure measurements were subtracted from the postexposure measurements, positive or negative results were possible. Therefore, an STS– or SES+ was defined as an improvement in hearing, whereas an STS+ or SES– represented a deterioration in hearing. Then, across frequencies, six 2×2 contingency tables using a χ^2 test were calculated ($P < .05$) to evaluate whether the occurrence of hearing deterioration differed between the control and each session of the noise exposure group. Finally, the odds ratios were determined as the odds of hearing deterioration in the noise exposure group divided by the odds of hearing deterioration in the control group.

Table 3. One-Hour Equivalent Continuous A-Weighted Noise Exposure at Different Gain Settings of the iPod Nano

Gain Setting, %	Equivalent Continuous A-Weighted Noise Exposure, dBA	
	Earbuds	Supra-aural Headphones
50	76.87	71.69
60	82.52	76.62
70	87.46	81.56
80	92.25	87.48
90	98.70	92.36
100	102.56	97.36

Abbreviation: dBA, A-weighted decibels.

RESULTS

OUTPUT MEASUREMENTS

At gain settings 50% to 100%, the $L_{Aeq,1h}$ of the iPod Nano ranges from 76.87 to 102.56 dBA for the earbuds and from 71.69 to 97.36 dBA for the supra-aural headphones (**Table 3**). For these gain settings, the earbuds were a mean (SD) of 5.55 (0.59) dB (range, 4.77-6.34 dB) higher than the supra-aural headphones. The 1/3-octave spectrum of both headphone styles at full gain setting is illustrated in **Figure 1**. At all 1/3-octave frequency bands, the output levels of the earbuds exceeded those of the supra-aural headphone except at 2.5 kHz. A distinct peak in the spectrum of the supra-aural headphones was seen at this frequency band. Table 1 summarizes the $L_{Aeq,T}$ for the whole CD and per track for both headphone styles at the full gain setting of the iPod Nano. The difference

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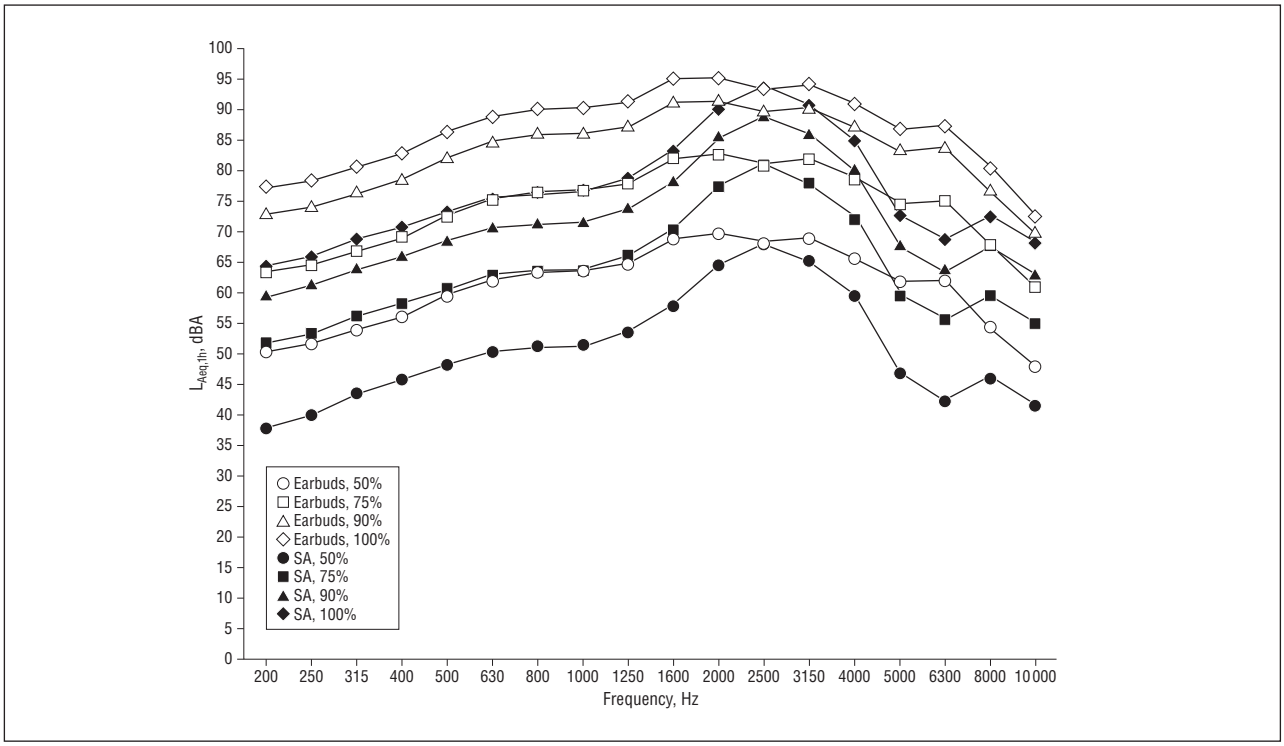

Figure 1. The 1-hour equivalent continuous A-weighted sound pressure level ($L_{Aeq,1h}$) at 1/3-octave frequency bands at various gain settings for the earbuds (open symbols) and supra-aural (SA) headphones (solid symbols). dBA indicates A-weighted decibels.

between the quietest and loudest tracks is 9.32 dB for the earbuds and 10.82 dB for the supra-aural headphones. Conversion of the $L_{Aeq,T}$ for 1 hour of pop-rock music to an 8-hour free-field corrected equivalent continuous SPL revealed levels for gain settings 50% to 100% ranging from 61.18 to 87.43 dBA and from 51.61 to 77.11 dBA for the stock iPod earbuds and the Sennheiser supra-aural headphones, respectively (Table 2).

HEARING MEASUREMENTS

Noise Exposure Group

Figure 2 displays group mean audiometric thresholds for preexposure and postexposure measurements, different headphone styles, and gain settings. A 3-way repeated-measures analysis of variance showed a significant 1.12-dB and 1.17-dB deterioration in hearing thresholds between preexposure and postexposure measurements at 0.25 kHz ($F_{1,14}$=7.00; $P<.05$) and 8.0 kHz ($F_{1,14}$=4.92; $P<.05$), respectively. There were no significant main effects at other frequencies. There was a significant 2-way measurement × headphone interaction only at 2.0 kHz ($F_{1,14}$=16.10; $P<.001$). A Bonferroni correction was applied to the results of the post hoc LSD test. Therefore, the familywise significance level $P<.05$ was divided by 2, representing the 2 comparisons of interest, yielding a significance level of $P<.025$. The hearing threshold deteriorated significantly ($P<.025$) with 1.78 dB between the preexposure and postexposure measurements for the supra-aural headphones. Furthermore, there was no significant 2-way interaction for measurement × volume nor was there a 3-way interaction.

Figure 3 shows the group mean TEOAE amplitudes for different headphones and gain settings at preexposure and postexposure measurements. Three-way repeated-measures analysis of variance indicated significant decreases in TEOAE amplitudes of –0.47 dB and –0.70 dB, respectively, at 2.0 kHz ($F_{1,14}$=6.89; $P<.05$) and 2.8 kHz ($F_{1,14}$=25.49; $P<.001$). There were also significant measurement × volume interactions at 2.8 kHz ($F_{2,28}$=7.45; $P<.01$) and 4.0 kHz ($F_{2,26}$=6.55; $P<.01$). The post hoc LSD tests with Bonferroni correction were used to establish the gain setting contributing to the measurement × volume interaction. Because 3 comparisons were of interest, a significance level of $P<.017$ was used, but no significant changes could be established. In addition, there were no other significant 2-way or 3-way interactions.

Group mean DPOAE amplitudes for earbuds and supra-aural headphones at gain settings 50%, 75%, and more than 75% for the preexposure and postexposure measurements are shown in **Figure 4**. There were no significant changes in DPOAE amplitudes for the main effect or for the 2-way interactions measurement × headphones or measurement × volume. However, there was a significant 3-way interaction at 8.0 kHz ($F_{2,22}$=4.65; $P<.05$). For the post hoc LSD tests, a significance level of $P<.008$ after Bonferroni correction (6 comparisons) was used. No significant effect could be established.

Recovery

One-way analysis of variance with a post hoc LSD test revealed no significant differences between the first and each consecutive preexposure measurement for hearing

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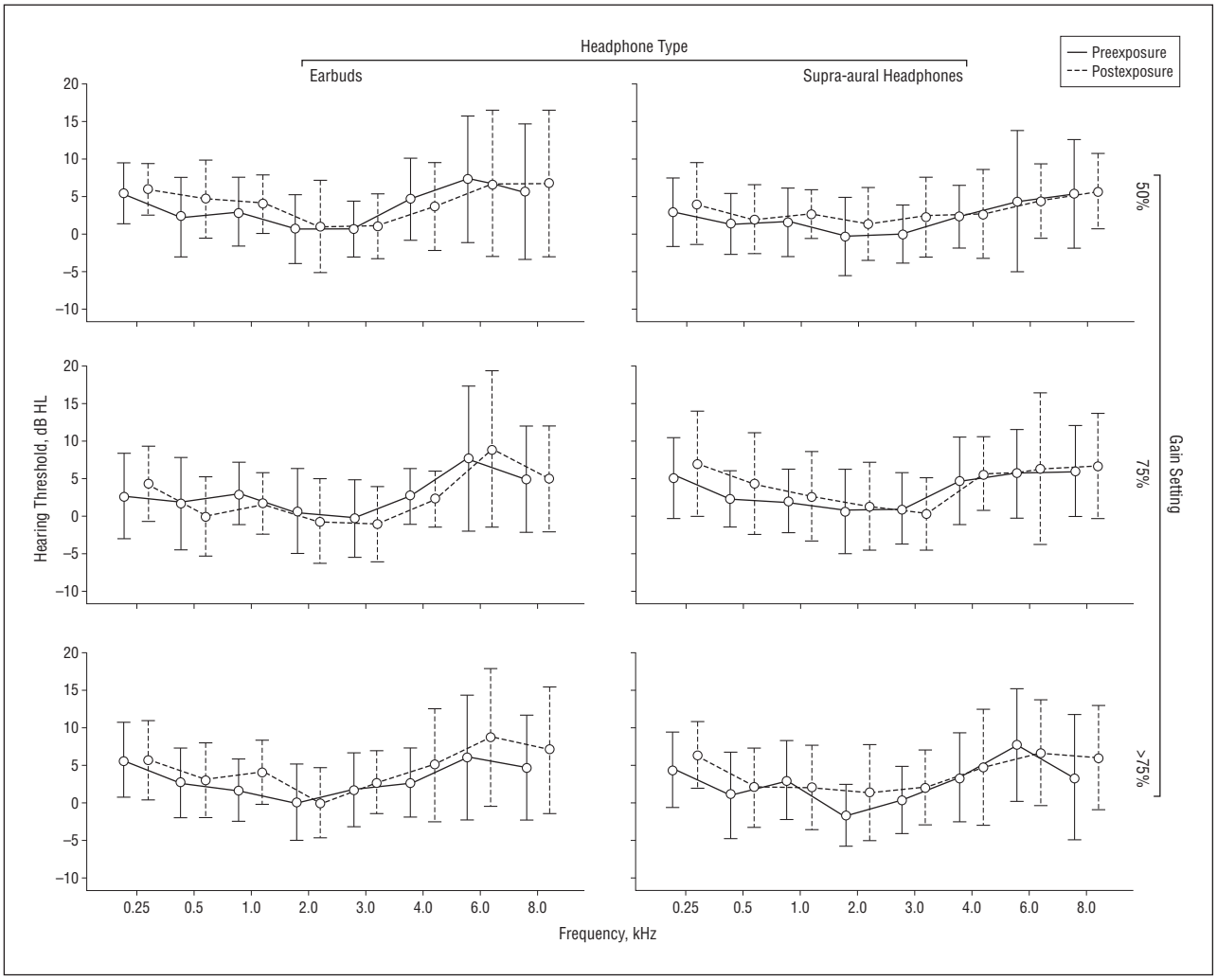

Figure 2. Mean (circles) (SD; [error bars]) of the hearing thresholds before (preexposure) and after (postexposure) listening to 1 hour of music at measured frequencies for both earphone styles and different gain settings. HL indicates hearing level.

thresholds or for TEOAE and DPOAE amplitudes at any test frequencies.

Individual Differences

The SEMs for pure-tone audiometry indicate higher variability at the lowest frequencies, 0.25 and 0.5 kHz, and highest frequencies, 6.0 and 8.0 kHz (**Table 4**). Despite this frequency dependency, the STSs equal 10 dB for all frequencies owing to rounding up to the next step. The χ^2 test revealed statistically significant differences in incidence of STS+ between the control group and each session of the noise exposure group except for the comparison between the controls and the session with earbuds at gain setting 75%. The odds for hearing deterioration were 4.40 and 3.97 times greater in the noise exposure group with earbuds at 50% (χ^2=22.19; P<.001) and above 75% (χ^2=17.00; P<.001), respectively, compared with the control group. For the supra-aural headphones, these odds were 3.87, 2.18, and 3.67 times larger for the noise exposure group with supra-aural headphones at 50% (χ^2=19.28; P<.001), 75% (χ^2=5.47; P<.05), and above 75% (χ^2=17.92; P<.001).

Table 5 shows the SEMs, SES criteria, and percentages of SESs– and SESs+ for the TEOAEs and DPOAEs at each half-octave frequency band. First, for the TEOAEs, the SEMs, and accordingly the SESs, are larger at the lowest frequency bands. The SES criteria range from 1.6 to 2.6 dB. Statistically significant results were found for the incidence of SESs– between the control group and each session of the noise exposure group except for the session with the supra-aural headphones at gain setting 75%. The SESs– were 0.44, 0.30, and 0.35 times more likely for the noise exposure group compared with the controls for the session with earbuds at 50% (χ^2=6.07; P<.05) and 75% (χ^2=12.25; P<.001) and supra-aural headphones at 50% (χ^2=9.33; P<.01), respectively. For the highest gain settings, the odds were 4.70 and 5.96 times greater in the noise exposure group with earbuds (χ^2=11.30; P<.001) and supra-aural headphones (χ^2=14.40; P<.001), respectively, compared with the control group. Second, the SEMs for DPOAEs are considerably higher at half-octave frequency bands 1.4 and 8.0 kHz. Accordingly, the SES criteria ranged from 0.9 to 3.2 dB. The χ^2 test was statistically significant for all comparisons between the control group and each session of

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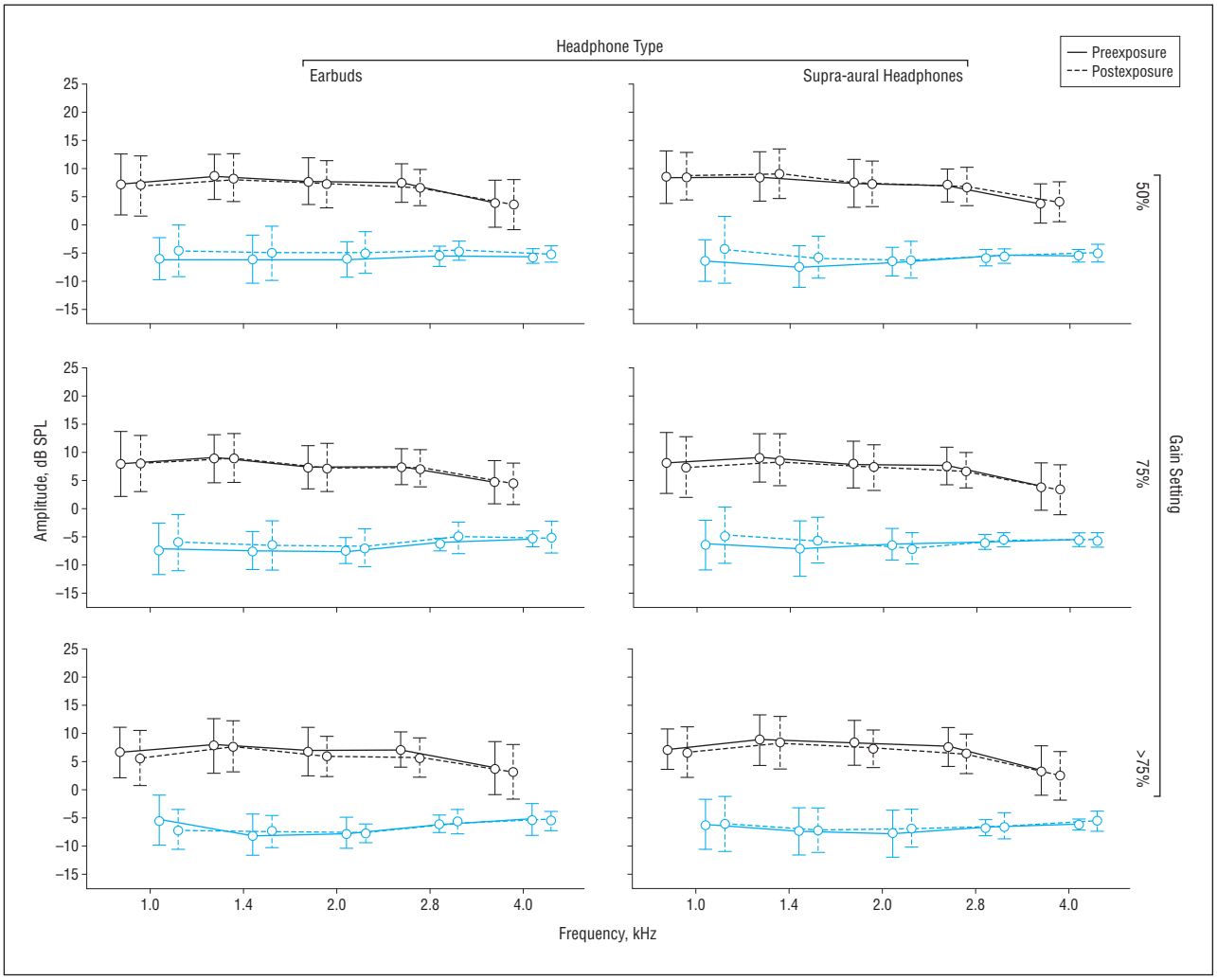

Figure 3. Mean (circles) (SD [error bars]) of the amplitude (black lines) and noise levels (blue lines) of the transient-evoked otoacoustic emissions before (preexposure) and after (postexposure) listening to 1 hour of music at frequency bands with center frequencies from 1.0 to 4.0 kHz are reflected for both earphone styles and different gain settings. SPL indicates sound pressure level.

the noise exposure group. The deterioration in DPOAEs was 2.64, 3.00, and 7.72 times higher for the noise exposure group with earbuds at 50% (χ^2=12.22; $P<.001$), 75% (χ^2=15.36; $P<.001$), and above 75% (χ^2=47.60; $P<.001$), respectively, than for the control group. Accordingly, the odds for SESs– were 2.36, 3.88, and 4.31 times greater for the supra-aural headphone sessions at 50% (χ^2=8.75; $P<.01$), 75% (χ^2=23.51; $P<.001$), and above 75% (χ^2=24.56; $P<.001$), respectively.

COMMENT

The popularity of PMPs has caused a widespread concern regarding their potentially hazardous effects on hearing. Literature regarding temporary hearing damage after listening to PMPs revealed some shortcomings, as well as considerable variability in methodological design. First, only a few studies account for the test-retest variability of the measurement technique by including a control group[24] or considering threshold shifts of at least 10 dB to be significant.[25] Second, user-preferred listening levels were generally determined with standard supra-aural headphones,[26-28] earbuds,[29] or user-preferred headphones[25] and were measured on an artificial ear with coupler[25] or via a miniature microphone in the external ear canal.[26,27,29] These levels were mostly free-field corrected.[26-28] Remarkably, 1 study on temporary threshold shift[24] did not perform output measurements to relate with the changes in hearing. Third, music exposure ranged from 1 hour to 3 hours with different genres of music.[24,25,30] Finally, changes in hearing sensitivity were mainly examined by means of audiometry; only 1 study measured synchronized spontaneous OAEs and DPOAEs following 30 minutes of rock music at 85 dBC (C-weighted).[29] Considering the differences in methods among and even within studies (eg, music genre varying among participants), it is difficult to make general statements regarding the short-term effects of listening to PMPs. Therefore, the present study evaluated the temporary changes in hearing by pure-tone audiometry, TEOAEs, and DPOAEs after 1 hour of listening to 1 music sample via multiple preset gain settings on 1 type of MP3 player and 2 different provided headphone styles. In the present study, no significant changes were seen between preexposure measurements, which indicates that the threshold and

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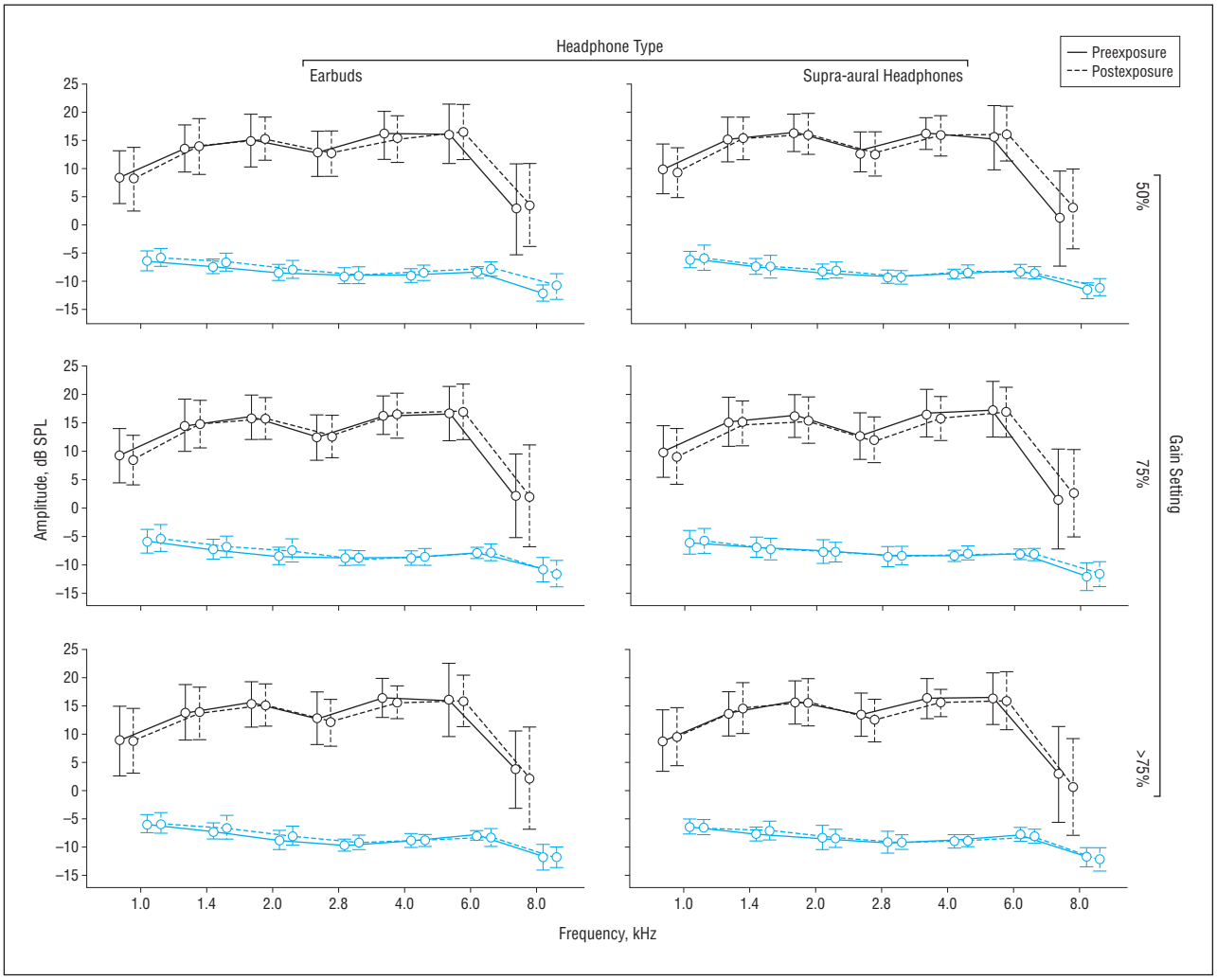

Figure 4. Mean (circles) (SD [error bars]) for the amplitude (black lines) and noise levels (blue lines) of the distortion product otoacoustic emissions before (preexposure) and after (postexposure) listening to 1 hour of music at measured frequencies for both earphone styles and different gain settings. SPL indicates sound pressure level.

Table 4. Percentage of STSs[a] for the Control Group and Noise Exposure Groups

Frequency, kHz	SEM, dB	STS, dB	Control Group, %		Noise Exposure Group and Gain Setting, %											
					Earbuds						Supra-aural Headphones					
					50		75		>75		50		75		>75	
			STS–	STS+	STS–	STS+	STS–	STS+	STS–	STS+	STS–	STS+	STS–	STS+	STS–	STS+
0.25	2.91	10	7.1	3.6	5.0	15.0	9.5	4.8	6.3	6.3	4.8	23.8	4.8	9.5	6.3	12.5
0.5	2.61	10	7.1	3.6	0.0	20.0	4.8	0.0	6.3	12.5	4.8	4.8	4.8	4.8	12.5	12.5
1.0	2.46	10	3.6	0.0	5.0	10.0	4.8	0.0	0.0	12.5	4.8	4.8	0.0	4.8	12.5	0.0
2.0	1.88	10	0.0	0.0	0.0	5.0	0.0	0.0	0.0	0.0	0.0	9.5	0.0	0.0	0.0	18.7
3.0	1.85	10	0.0	0.0	0.0	15.0	14.3	0.0	0.0	6.3	0.0	14.3	9.5	0.0	0.0	12.5
4.0	2.63	10	3.6	7.1	10.0	0.0	4.8	0.0	12.5	12.5	4.8	9.5	9.5	14.3	0.0	18.7
6.0	2.92	10	10.7	3.6	15.0	5.0	19.0	19.0	6.3	6.3	14.3	14.3	9.5	14.3	12.5	6.3
8.0	2.89	10	10.7	3.6	5.0	20.0	4.8	4.8	0.0	6.3	14.3	14.3	4.8	0.0	6.3	12.5

Abbreviations: SEM, standard error of measurement; STS, significant threshold shift.
[a]The STSs are derived from the SEM for each frequency and reflect the improvement (STS–) or deterioration (STS+) of the audiometric thresholds.

emission shifts were temporary and that these shifts recovered to preexposure baseline measurements between the sessions.

The results of this study revealed a statistically significant main effect preexposure and postexposure for the TEOAEs at 2.0 and 2.8 kHz, whereas no significant

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Table 5. Percentage of SESs[a] for Both OAE Types

OAE Type and Frequency, kHz	SEM, dB	SES, dB	Control Group, %		Noise Exposure Group and Gain Setting, %											
					Earbuds						Supra-aural Headphones					
					50		75		>75		50		75		>75	
			SES–	SES+	SES–	SES+	SES–	SES+	SES–	SES+	SES–	SES+	SES–	SES+	SES–	SES+
TE																
1.0	0.76	2.2	7.1	3.6	20.0	15.0	14.3	23.8	20.0	6.7	15.0	15.0	28.6	4.8	25.0	6.3
1.4	0.92	2.6	3.7	7.4	9.5	14.3	4.8	14.3	0.0	0.0	4.8	14.3	14.3	0.0	0.0	0.0
2.0	0.74	2.1	14.3	3.6	9.5	9.5	14.3	4.8	18.8	0.0	14.3	4.8	14.3	4.8	20.0	0.0
2.8	0.57	1.6	17.9	0.0	28.6	4.8	4.8	4.8	37.5	0.0	14.3	14.3	33.3	9.5	33.3	0.0
4.0	0.58	1.7	3.8	0.0	20.0	20.0	11.1	5.6	26.7	0.0	10.5	5.3	25.0	5.0	33.3	0.0
DP																
1.0	0.69	2.0	0.0	14.3	30.0	15.0	33.3	4.8	12.5	12.5	19.0	0.0	19.0	4.8	6.3	12.5
1.4	1.15	3.2	0.0	7.1	15.0	20.0	4.8	4.8	0.0	0.0	0.0	9.5	9.5	0.0	0.0	0.0
2.0	0.67	1.9	3.6	3.6	15.0	20.0	9.5	4.8	0.0	0.0	4.8	4.8	19.0	19.0	6.3	0.0
2.8	0.77	2.2	7.1	3.6	5.0	15.0	14.3	14.3	12.5	0.0	14.3	9.5	19.0	14.3	18.8	0.0
4.0	0.52	1.5	3.8	7.7	30.0	15.0	19.0	19.0	37.5	0.0	19.0	19.0	28.6	4.8	25.0	18.8
6.0	0.30	0.9	0.0	7.1	40.0	25.0	42.9	28.6	50.0	12.5	28.6	33.3	38.1	23.8	37.5	18.8
8.0	0.97	2.8	7.1	3.6	27.8	22.2	25.0	30.0	28.6	14.3	20.0	20.0	26.3	21.1	21.4	7.1

Abbreviations: DP, distortion product; OAE, otoacoustic emission; SEM, standard error of measurement; SES, significant emission shift; TE, transient evoked.
[a]The SESs are derived from the SEM and indicate a deterioration (SES–) or improvement (SES+) of OAEs.

mean changes were found for the DPOAEs. However, the odds ratios of hearing deterioration in the noise exposure group compared with the control group were higher for the DPOAEs than the TEOAEs. Also, the occurrence of significant DPOAE shifts were mostly seen at 6.0 kHz, which has been previously reported.[29] A possible explanation for the difference in sensitivity for NIHL between the OAE types can be explained by the higher test-retest reliability of DPOAEs compared with TEOAEs[31] and by the generation mechanism of both OAEs. In the present study, DPOAEs were measured at 8 points per octave to preserve their frequency specificity and then averaged into half-octave frequency bands. Hence, reliability was increased, and the shift required to be significant was reduced. As such, the sensitivity of DPOAEs to detect minimal cochlear damage may be higher than at individual frequencies in DPOAE measurements.[29] Moreover, direct comparison with TEOAEs in half-octave frequency bands from 1.0 to 4.0 kHz became possible. Three of 5 half-octave frequency bands had lower SEM values for the DPOAEs than the TEOAEs but failed to reveal any significant mean changes in cochlear function after noise exposure. This might indicate that the generation mechanisms seem to be the dominating factor. The OAEs are a mixture of emissions produced by linear reflection and nonlinear distortion.[32] Because of these differences in generation mechanisms between the OAE types, it is plausible that outer hair cell damage after noise exposure is better detected with TEOAEs than with DPOAEs. This is consistent with the hypothesis of Shera.[32] However, DPOAEs were measured with the primary tone level combination L1/L2=75/70-dB SPL. At these high-level primaries, test-retest reliability of DPOAE amplitudes is higher[33] but their sensitivity for inner ear changes might decrease.[34] Primary tone levels in the range of 60/35-dB SPL or 55/30-dB SPL are suggested. However, the delivered stimuli of the DPOAEs are restricted to 40-dB SPL for the ILO 288 USB II module, making use of this range of stimuli levels impossible. Moreover, by reducing the stimulus levels, the signal to noise ratio lowers and, consequently, the amount of missing data would increase, which was obviously not desired in the present study. Furthermore, it must be emphasized that hearing measurements were conducted in a fixed order. Therefore, it is possible that TEOAEs and DPOAEs, even within the 10 minutes after the listening session, were performed at different points in the recovery process,[35] which could also explain the difference in sensitivity of both types of OAEs to noise exposure.

There was also a statistically significant worsening of audiometric thresholds after the listening sessions at 0.25 and 8.0 kHz. Increased SEM values were also noticed at these lowest and highest frequencies. The tension of the headband and resiliency of the earphone cushion can result in a small displacement of the earphone, which could be a source of variability between preexposure and postexposure measurements. For OAEs however, it is possible to control the probe fitting to some extent using the stimulus check procedure, which visualizes the stimulus oscillogram and spectrum. A biphasic stimulus oscillogram without a significant amount of ringing and a flat stimulus spectrum should be aimed for at the first measurement in one ear. At any successive measurement, a similar stimulus pattern should be achieved. Besides this test-retest variability, audiometry is clinically measured with a 5-dB step size. Thus, although there is a smaller test-retest variability at the midfrequencies 1.0 to 4.0 kHz, only changes in hearing thresholds of at least 10 dB can be considered to be significant owing to this step size. This possibly explains why small changes in hearing sensitivity cannot be detected using audiometry. Furthermore, audiometry requires a subjective response by the participant and assesses the entire auditory system. In contrast, OAEs are an objective measure

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of the cochlear integrity, and are able to detect inner ear changes before hearing is affected. LePage[36] mentioned the theory of hair cell redundancy and hypothesized that a small amount of hair cell damage is not detected by audiometry because only a few cells are needed for hearing at threshold. However, the TEOAE stimulus activates all outer hair cells, and, therefore, even a small amount of hair cell damage reduces the TEOAE amplitude. Again, it must be emphasized that hearing measurements were conducted in a fixed order, and there could be a slight underestimation of the amount of temporary threshold shift because of this methodological design.

Besides these main effects, there was a statistically significant deterioration of the hearing thresholds at 2.0 kHz between the preexposure and postexposure measurements for the supra-aural headphones. The 1/3-octave spectrum of the supra-aural headphones shows a higher peak around 2.5 kHz, which could attribute to this interaction effect. The difference in spectra can largely be explained by the differences in physical and electronic coupling between the 2 earphone styles. The resonance of the concha using the supra-aural headphone can result in a resonance peak at approximately 2.5 kHz. Nevertheless, the odds for hearing deterioration were almost equal for both headphone styles compared with the control group. For OAEs, no statistically significant measurement × headphone interactions were found across half-octave frequency bands. So, although the earbud had on average 5.5-dB higher output levels and different spectral composition than the supra-aural headphones, using earbuds did not result in larger mean shifts or in higher incidence of temporary threshold or emission shifts.

No statistically significant measurement × volume interaction effects were found for pure-tone audiometry or for the OAEs. However, the highest odds for OAE deterioration were seen at gain settings above 75% compared with the control group, which was not seen for pure-tone audiometry. Previously, A-weighted free-field maximum SPLs measured using an acoustic manikin reached 101 to 107 dBA for MP3 players.[5] Also, the maximum SPLs for an MP3 player with earbuds reached 110.5 dBA.[4] It is, however, not clear whether this maximum level was determined by the device or the maximum tolerable level for the author. Nevertheless, our MP3 player did not reach such levels. There are several possible explanations. First, Hodgetts et al[4] used real ear measurements to determine the output level, implying the possibility that individual ear canal acoustics could be responsible for the higher output level. Second, the output level can differ across manufacturers,[37] and, finally, a French law[38] states that the maximum output level of MP3 players should be limited to 100-dB SPL. Therefore, it could be possible that the European iPods have a lower output level compared with those manufactured for markets outside Europe.

Conversions of the 1 hour of pop-rock music from the iPod Nano at maximum gain setting to an 8-hour free-field corrected equivalent SPL were 77 and 88 dBA for the Sennheiser supra-aural headphone and stock iPod earbuds, respectively. These levels exceed the 75-dBA level, which represents negligible risk for acquiring NIHL and, for the stock iPod earbuds, the lowest threshold for action (80 dBA) as stated in the European Directive.[21] Some authors do not justify the extrapolation of occupational risk criteria to leisure noise exposures owing to the differences in spectral and temporal pattern.[30,37] Because the regulation is based on the exposure level and duration of noise exposure and no criteria are available for leisure noise exposure, an $L_{Aeq,8h}$ of 80 dBA using a 3-dB exchange rate is, with some reservations, applicable to the results of PMPs. However, other standards (eg, those of the US Occupational Safety and Health Administration) use a 5-dB exchange rate, which could be more appropriate for music than the 3-dB exchange rate.[28] In the present study, the equivalent SPL was integrated for the duration of the whole CD and, hence, accounted for the quiet pauses between songs. This is more representative than measuring the output per track or for a specified period. However, the criterion does not account for longer listening sessions or for user-preferred listening levels, which depend on the presence of background noise,[11] the type of music,[37] the earphone style,[37,39] and the personal music device.[37] The output levels measured in the present study are limited to the specific type of MP3 player and headphone styles used, although both were chosen on the basis of the "best sale" recommendation of a Belgian consumer's guide and their popularity. The iPod Nano shows a linearity in the volume control, whereas this is not necessarily the case for other devices.[28] The difference in output levels between the earbuds and supra-aural headphones confirms the results of Fligor and Cox[37] but is less pronounced. Furthermore, the current levels are limited to the music sample used in the study, which was also selected because of its popularity but cannot be generalized to other music genres. Also, even within the same genre, differences of 9.32 and 10.82 dB are noticed between the quietest and loudest tracks.

The goal of the present study was to evaluate the temporary changes in hearing after 1 hour of listening to an MP3 player. Possibilities for future research include an analysis of sex differences in temporary hearing deterioration after noise exposure. Furthermore, the development of a permanent threshold shift cannot be predicted from the initial temporary threshold shift, but, considering the reduction in hearing sensitivity after listening to a PMP, these devices are potentially harmful. Further research is needed to evaluate the long-term risk of cumulative recreational noise exposures. A careful inventory of the leisure activities and corresponding listening habits as well as hearing tests should be conducted with a representative sample. Based on the results of the present study, we recommend using OAEs in complement with audiometry for the assessment of hearing status.

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Correspondence: Hannah Keppler, MS, Ear, Nose, and Throat Department, Faculty of Medicine and Health Sciences, Ghent University, De Pintelaan 185, 9000 Ghent, Belgium (hannah.keppler@ugent.be).

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Author Contributions: Ms Keppler and Drs Dhooge and Vinck had full access to all the data in the study and take responsibility for the integrity of the data and the accuracy of the data analysis. *Study concept and design*: Keppler, Dhooge, and Vinck. *Acquisition of data*: Keppler. *Analysis and interpretation of data*: Keppler, Maes, D'haenens, Bockstael, Philips, and Swinnen. *Drafting of the manuscript*: Keppler, Maes, D'haenens, Bockstael, Philips, and Swinnen. *Critical revision of the manuscript for important intellectual content*: Dhooge and Vinck. *Statistical analysis*: Keppler. *Administrative, technical, and material support*: Keppler, Maes, D'haenens, Bockstael, Philips, and Swinnen. *Study supervision*: Dhooge and Vinck.
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REFERENCES

1. Niskar AS, Kieszak SM, Holmes AE, Esteban E, Rubin C, Brody DJ. Estimated prevalence of noise-induced hearing threshold shifts among children 6 to 19 years of age: the Third National Health and Nutrition Examination Survey, 1988-1994, United States. *Pediatrics*. 2001;108(1):40-43.
2. Rabinowitz PM, Slade MD, Galusha D, Dixon-Ernst C, Cullen MR. Trends in the prevalence of hearing loss among young adults entering an industrial workforce 1985 to 2004. *Ear Hear*. 2006;27(4):369-375.
3. Axelsson A, Prasher D. Tinnitus: a warning signal to teenagers attending discotheques? *Noise Health*. 1999;1(2):1-2.
4. Hodgetts WE, Rieger JM, Szarko RA. The effects of listening environment and earphone style on preferred listening levels of normal hearing adults using an MP3 player. *Ear Hear*. 2007;28(3):290-297.
5. Keith SE, Michaud DS, Chiu V. Evaluating the maximum playback sound levels from portable digital audio players. *J Acoust Soc Am*. 2008;123(6):4227-4237.
6. Passchier-Vermeer W. Pop music through headphones and hearing loss. *Noise Control Eng J*. 1999;47(5):182-186.
7. Medical Research Council Institute of Hearing Research. Damage to hearing arising from leisure noise. *Br J Audiol*. 1986;20(2):157-164.
8. Rice CG, Rossi G, Olina M. Damage risk from personal cassette players. *Br J Audiol*. 1987;21(4):279-288.
9. Clark WW. Noise exposure from leisure activities: a review. *J Acoust Soc Am*. 1991;90(1):175-181.
10. Catalano PJ, Levin SM. Noise-induced hearing loss and portable radios with headphones. *Int J Pediatr Otorhinolaryngol*. 1985;9(1):59-67.
11. Williams W. Noise exposure levels from personal stereo use. *Int J Audiol*. 2005; 44(4):231-236.
12. Meyer-Bisch C. Epidemiological evaluation of hearing damage related to strongly amplified music (personal cassette players, discotheques, rock concerts): high-definition audiometric survey on 1364 subjects. *Audiology*. 1996;35(3):121-142.
13. LePage EL, Murray NM. Latent cochlear damage in personal stereo users: a study based on click-evoked otoacoustic emissions. *Med J Aust*. 1998;169(11-12): 588-592.
14. Mostafapour SP, Lahargoue K, Gates GA. Noise-induced hearing loss in young adults: the role of personal listening devices and other sources of leisure noise. *Laryngoscope*. 1998;108(12):1832-1839.
15. Smith PA, Davis A, Ferguson M, Lutman ME. The prevalence and type of social noise exposure in young adults in England. *Noise Health*. 2000;2(6):41-56.
16. Serra MR, Biassoni EC, Richter U, et al. Recreational noise exposure and its effects on the hearing of adolescents, part I: an interdisciplinary long-term study. *Int J Audiol*. 2005;44(2):65-73.
17. Talaska AE, Schacht J. Mechanisms of noise damage to the cochlea. *Audiol Med*. 2007;5(1):3-9. doi:10.1080/16513860601158887.
18. Nordmann AS, Bohne BA, Harding GW. Histopathological differences between temporary and permanent threshold shift. *Hear Res*. 2000;139(1-2):13-30.
19. Sliwinska-Kowalska M, Kotylo P. Evaluation of individuals with known or suspected noise damage to hearing. *Audiol Med*. 2007;5(1):54-65. doi:10.1080/16513860601181442.
20. Marshall L, Lapsley Miller JA, Heller LM. Distortion-product otoacoustic emissions as a screening tool for noise-induced hearing loss. *Noise Health*. 2001; 3(12):43-60.
21. European Parliament and Council. Directive 2003/10/EC on the minimum health and safety requirements regarding the exposure of workers to the risks arising from physical agents (noise). *OJ Eur Union*. February 15, 2003;46(L42): 38-44.
22. Hammershoi D, Moller H. Determination of noise immission from sound sources close to the ears. *Acta Acustica*. 2008;94(1):114-129.
23. Lapsley Miller JA, Marshall L, Heller LM. A longitudinal study of changes in evoked otoacoustic emissions and pure-tone thresholds as measured in a hearing conservation program. *Int J Audiol*. 2004;43(6):307-322.
24. Pugsley S, Stuart A, Kalinowski J, Armson J. Changes in hearing sensitivity following portable stereo system use. *Am J Audiol*. 1993;2:64-67.
25. Lee PC, Senders CW, Gantz BJ, Otto SR. Transient sensorineural hearing loss after overuse of portable headphone cassette radios. *Otolaryngol Head Neck Surg*. 1985;93(5):622-625.
26. Hellström PA. The effects on hearing from portable cassette players: a follow-up study. *J Sound Vibrat*. 1991;151(3):461-469. doi:10.1016/0022-460X(91)90545-U.
27. Hellström PA, Axelsson A, Costa O. Temporary threshold shift induced by music. *Scand Audiol Suppl*. 1998;48:87-94.
28. Turunen-Rise I, Flottorp G, Tvete O. Personal cassette players ("Walkman"): do they cause noise-induced hearing loss? *Scand Audiol*. 1991;20(4):239-244.
29. Bhagat SP, Davis AM. Modification of otoacoustic emissions following ear-level exposure to MP3 player music. *Int J Audiol*. 2008;47(12):751-760.
30. Turunen-Rise I, Flottorp G, Tvete O. A study of the possibility of acquiring noise-induced hearing loss by the use of personal cassette players (Walkman). *Scand Audiol Suppl*. 1991;34:133-144.
31. Lapsley Miller JA, Marshall L. Monitoring the effects of noise with otoacoustic emissions. *Semin Hear*. 2001;22(4):393-403.
32. Shera CA. Mechanisms of mammalian otoacoustic emission and their implications for the clinical utility of otoacoustic emissions. *Ear Hear*. 2004;25(2): 86-97.
33. Franklin DJ, McCoy MJ, Martin GK, Lonsbury-Martin BL. Test/retest reliability of distortion-product and transiently evoked otoacoustic emissions. *Ear Hear*. 1992;13(6):417-429.
34. Sutton LA, Lonsbury-Martin BL, Martin GK, Whitehead ML. Sensitivity of distortion-product otoacoustic emissions in humans to tonal over-exposure: time course of recovery and effects of lowering L2. *Hear Res*. 1994;75(1-2):161-174.
35. Marshall L, Heller LM. Transient-evoked otoacoustic emissions as a measure of noise-induced threshold shift. *J Speech Lang Hear Res*. 1998;41(6):1319-1334.
36. LePage EL. Occupational noise-induced hearing loss: origin, characterisation and prevention. *Acoust Aust*. 1998;26(2):57-61.
37. Fligor BJ, Cox LC. Output levels of commercially available portable compact disc players and the potential risk to hearing. *Ear Hear*. 2004;25(6):513-527.
38. Code de la santé publique: dispositifs médicaux de diagnostic in vitro et autres produits et objets réglementés dans l'intérêt de la santé publique. Loi 2004-806, article L5232-1. (2004). http://www.legifrance.gouv.fr/affichCodeArticle.do;jsessionid=1077C3C9C7F9989D2EAE1700E68866C8.tpdjo06v_3?idArticle=LEGIARTI000006690338&cidTexte=LEGITEXT000006072665&dateTexte=20100413. Accessed February 10, 2009.
39. MacLean GL, Stuart A, Stenstrom R. Real ear sound pressure levels developed by three portable stereo system earphones. *Am J Audiol*. November 1992; 1:52-55.

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