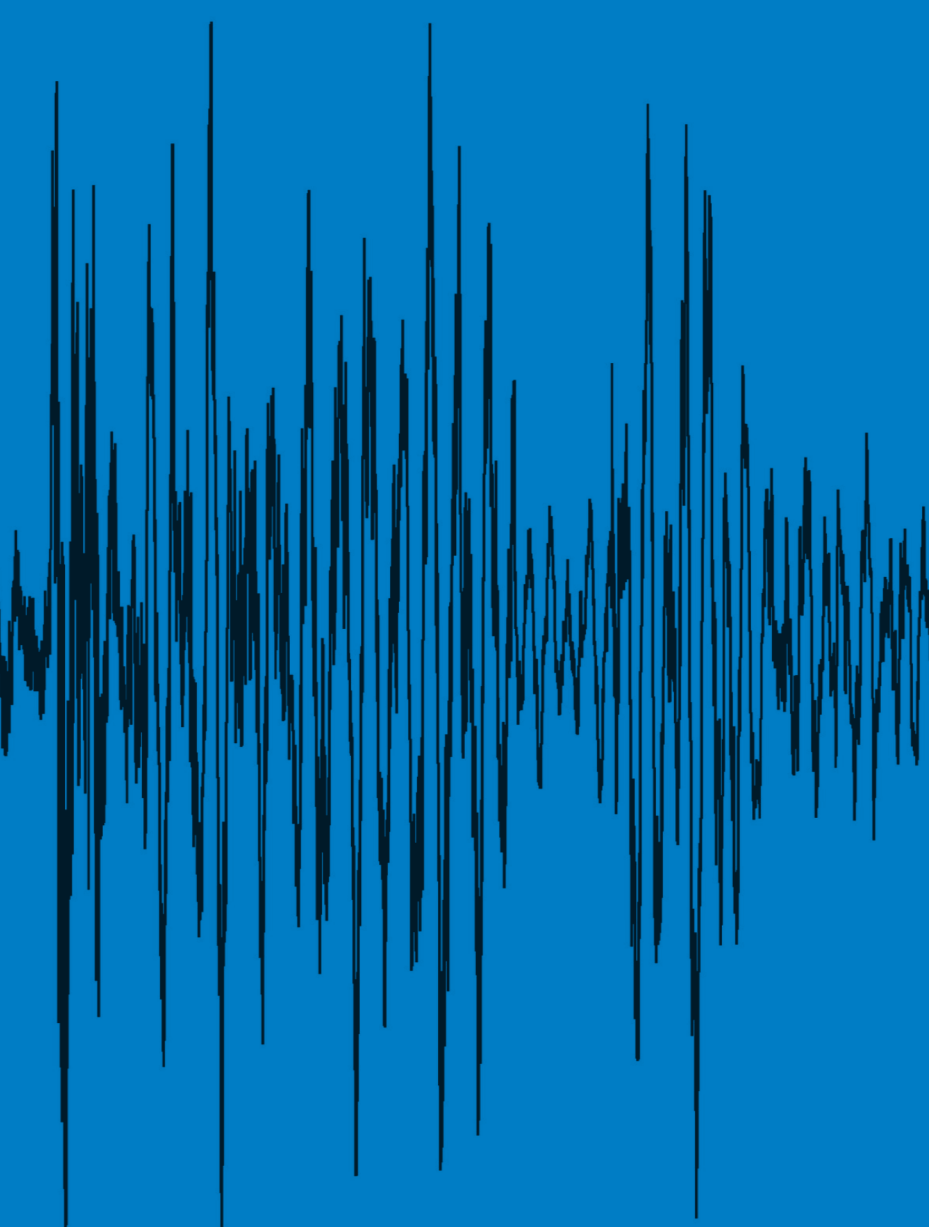


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Hearing in young adults. Part II: The effects of recreational noise exposure

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Abstract

Great concern arises from recreational noise exposure, which might lead to noise-induced hearing loss in young adults. The objective of the current study was to evaluate the effects of recreational noise exposure on hearing function in young adults. A questionnaire concerning recreational noise exposures and an audiological test battery were completed by 163 subjects (aged 18-30 years). Based on the duration of exposure and self-estimated loudness of various leisure-time activities, the weekly and lifetime equivalent noise exposure were calculated. Subjects were categorized in groups with low, intermediate, and high recreational noise exposure based on these values. Hearing was evaluated using audiometry, transient-evoked otoacoustic emissions (TEOAEs), and distortion-product otoacoustic emissions (DPOAEs). Mean differences in hearing between groups with low, intermediate, and high recreational noise exposure were evaluated using one-way analysis of variance (ANOVA). There were no significant differences in hearing thresholds, TEOAE amplitudes, and DPOAE amplitudes between groups with low, intermediate, or high recreational noise exposure. Nevertheless, one-third of our subjects exceeded the weekly equivalent noise exposure for all activities of 75 dBA. Further, the highest equivalent sound pressure levels (SPLs) were calculated for the activities visiting nightclubs or pubs, attending concerts or festivals, and playing in a band or orchestra. Moreover, temporary tinnitus after recreational noise exposure was found in 86% of our subjects. There were no significant differences in hearing between groups with low, intermediate, and high recreational noise exposure. Nevertheless, a long-term assessment of young adults' hearing in relation to recreational noise exposure is needed.

Keywords: Attitudes, hearing, hearing protector devices (HPDs), noise-induced hearing loss (NIHL), recreational noise exposure, young adults

Introduction

Prolonged, excessive noise exposure can induce metabolic and mechanical changes in the organ of Corti^[1,2] leading to noise-induced hearing loss (NIHL).^[3] While the prevalence of occupational noise has decreased since the early 1980s, the prevalence of social noise has tripled.^[4] There is great concern regarding the development of NIHL in youth due to high sound exposure levels during leisure-time activities. Maximum equivalent continuous output levels of personal music players (PMPs) range between 97 dBA and 103 dBA for earbuds and supraaural headphones, respectively.^[5] Sound intensity levels at concerts and

clubs can amount up to 105 dBA^[6-10] and 112 dBA,^[10-17] respectively.

Research regarding the prevalence of NIHL due to recreational noise has revealed some inconsistent results. Some studies reported an increase in prevalence of high-frequency hearing loss, which was attributed to recreational noise exposure,^[18-20] while others have not found such results.^[21-24] These inconsistencies can be attributed to methodological difficulties in the accurate estimation of the number of subjects exposed, and in obtaining a sample of young individuals with representative sound levels, patterns, and duration of exposure.^[25] Furthermore, the criteria to define hearing impairment should be based on pure-tone averages or audiogram notches in combination with a positive history of noise exposure.^[26-29] However, in some studies, no conclusive data regarding recreational noise exposure are provided.^[20,30] Finally, there are numerous medical confounding factors with regard to hearing loss, as well as social factors that make the design of such research complicated.^[29] It is noteworthy that there are inconsistencies even in studies using the same cohort, but applying a different set of exclusion criteria.^[20,24,28]

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Future studies estimating the prevalence of NIHL due to recreational noise should be optimized by taking into account these methodological difficulties.

Besides epidemiological research, several investigators investigated the association between recreational noise exposure and hearing loss. Some studies found a high-frequency deterioration of hearing, which was attributed to recreational noise exposure.^[31-36] Other studies found no correlation or only a slight correlation between hearing loss and recreational noise exposure.^[37-46] A possible explanation for this lack of hearing deterioration due to recreational noise exposure is that risk assessment is based on occupational risk criteria, which might overestimate the actual risk of loud music listening due to the differences in spectrum, and temporal and dynamic variation in music compared to occupational noise.^[47-50] Risk assessment is also liable to attitudes and beliefs regarding noise exposure, hearing loss, and hearing protector devices (HPDs). Subjects with attitudes where noise or hearing loss was seen as unproblematic and attitudes and beliefs regarding HPDs were worse had significantly more deteriorated hearing than did those with neutral or negative attitudes and beliefs.^[51] Further, risk assessment is complicated by the interaction of noise exposure and listening or attendance habits in the context of multiple leisure activities. Nevertheless, some studies only emphasized the role of PMPs^[52,53] or concerts^[54] in the development of NIHL, without considering other leisure activities. Besides these difficulties in risk assessment, most of the studies used pure-tone audiometry, although its sensitivity for the early detection of NIHL has been questioned.^[55-58] Otoacoustic emissions (OAEs), reflecting the integrity of the cochlear outer hair cells,^[59] are suggested as promising tools in the detection of preclinical hearing loss^[60,61] and could therefore be included in recreational noise-exposure studies.^[62]

In summary, the literature is not conclusive regarding the relationship between recreational noise exposure and hearing damage in youth. Therefore, the current study was undertaken to evaluate the effect of recreational noise exposure on young adults' hearing. First, various leisure activities were considered with regard to duration of exposure and self-estimated loudness. It was hypothesized that the accumulation of noise exposure during multiple leisure activities might affect hearing. Second, hearing was assessed using (high-frequency) pure-tone audiometry and evoked OAEs to detect possible hearing loss in a preclinical stage.

Methods

Subjects

The study population consisted of 163 young adults ranging in age between 18 years and 30 years. The mean ages of the females and males were respectively 20.81 years [standard deviation (SD) 2.72 years] and 22.69 years (SD 3.01 years).

All subjects were recruited through convenience sampling at Ghent University, University College Ghent, and Ghent University Hospital (Belgium). The majority of the participants were students (84.7%). All subjects voluntarily participated in the study, which consisted of a questionnaire and hearing assessment performed during a single session. A noise-free period of at least 24 h before testing was required. Hearing assessment took place in a double-walled, sound-attenuated booth and consisted of an otoscopic evaluation, admittance measures, pure-tone audiometry, and measuring OAEs. Both ears per subject were tested, but statistical analysis was only performed on one ear randomly selected.

The inclusion criteria of the study were normal otoscopic examination and normal middle-ear function by admittance measures.

The study was approved by the local Ethical Committee and all subjects provided informed consent in accordance with the statements of the Declaration of Helsinki.

Questionnaire

The questionnaire was based on literature regarding recreational noise exposure, and attitudes and beliefs towards noise, hearing loss, and HPDs.^[63-66] The first Dutch version was pretested using a semistructured interview, whereas the refined second version was evaluated on paper. A total of 61 subjects ranging in age between 18 years and 30 years participated in the pretesting of the questionnaire; they were not included in the current study. The final version of the questionnaire contained five parts.

The first part consisted of questions regarding the subjective assessment of hearing, and hearing-related symptoms such as tinnitus, hearing impairment, pain, and noise sensitivity. Knowledge and concern regarding NIHL caused by recreational noise exposure was also questioned.

Second, sources of recreational noise exposure were evaluated in time spent per week or month (h), the total time of exposure (in years), and subjective estimation of loudness. The scale of loudness referred to the following sound levels:

1. That of a normal conversation,
2. That of a loud conversation,
3. That at which one must shout over 1 m,
4. That at which one must shout over a near distance, and
5. That which makes communication impossible.

This self-estimated loudness corresponded to A-weighted equivalent sound pressure levels (SPLs) ranging from 60 dBA to 100 dBA for ratings 1 to 5, respectively. The weekly equivalent noise exposure per activity was calculated as $L_{Aeq,w} = L_{Aeq} + 10 \cdot \log_{10} (T_w/T_0)$, where L_{Aeq} represented the A-weighted equivalent SPLs from 60 dBA to 100 dBA, T_w the time spent per week in h, and T_0 the 40-h reference of a workweek. Accordingly, the lifetime equivalent noise

exposure per activity was computed as $L_{Aeq,l} = L_{Aeq,w} + 10 \cdot \log_{10}(T_y)$, where T_y reflected the time of exposure in years. The weekly and lifetime equivalent noise exposures for all activities ($L_{Aeq,w,all}$ and $L_{Aeq,l,all}$) were determined by calculating the logarithm of the average $L_{Aeq,w}$ and $L_{Aeq,l}$ in Pa, respectively. The methods to estimate weekly and lifetime equivalent noise exposures were adopted from Jokitalo *et al.*, 2006.^[64] Based on the quartiles of the $L_{Aeq,w,all}$ and $L_{Aeq,l,all}$, subjects were divided in three groups, where the lower quartile, the two middle quartiles, and the upper quartile represented subjects with low, intermediate, and high recreational noise exposure, respectively.

In the third part of the questionnaire, the use of PMPs was investigated using questions about the type of PMP and headphones, the typical duration of a listening session, the type of music, the typical volume on a visual analog scale, usage during transportation, and particular emotions.

Fourth, attitudes regarding noise, hearing loss, and HPDs were evaluated by a modified version of the “Youth Attitude to Noise Scale” and “Beliefs about Hearing Protection and Hearing Loss,” respectively.^[67] These results are presented elsewhere.^[51]

Finally, gender, age, education or profession, and parental employment were questioned.

Admittance measures

Admittance measurements consisted of tympanometry, which was performed using an 85 dB SPL 226 Hz probe tone, and ipsilateral and contralateral acoustic stapedial reflexes measured at 1.0 kHz (TympStar, Grason-Stadler Inc., Minnesota, USA).

Audiometric evaluation

The modified Hughson-Westlake method for air-conduction thresholds (Orbiter 922 Clinical Audiometer, MADSEN Electronics, Taastrup, Denmark) was used at conventional octave frequencies 0.25-8.0 kHz; half-octave frequencies 3.0 kHz and 6.0 kHz; and extended high-frequencies 10.0 kHz, 12.5 kHz, and 16 kHz using HDA 200 headphones (Sennheiser, Connecticut, USA).

OAEs

Transient-evoked OAEs (TEOAEs) and distortion-product OAEs (DPOAEs) were measured using the ILO292 USB II module coupled with a laptop with ILO V6 software (Otodynamics Ltd., Hatfield, UK). Calibration of the DPOAE probe was regularly done using the 1 cc calibration cavity provided by the manufacturer.

For TEOAE measurements, the nonlinear differential method of stimulation was used. Rectangular pulses of 80 μ s at a rate of 50 clicks/s were delivered at an intensity of 80 ± 2 dBpeSPL. The registration of TEOAEs was terminated after

260 accepted sweeps, with a noise rejection setting of 4 mPa. Emission and noise amplitudes were calculated in half-octave frequency bands centred at 1.0 kHz, 1.5 kHz, 2.0 kHz, 3.0 kHz, and 4.0 kHz. A probe stability of 90% or better was needed, and TEOAEs were considered present if the signal-to-noise ratio (SNR) was at least 3 dB at each half-octave frequency band, separately or across frequencies.

DPOAEs were measured with simultaneous presentation of two primary tones with primary tone level combination L1/L2 = 65/55 dB SPL at eight points per octave. The ratio of primary tone frequencies f_2/f_1 equaled 1.22, and f_2 ranged 0.841-8.0 kHz. A noise artefact rejection level of 6 mPa was used and the whole frequency range was looped until the noise amplitude fell below -5 dB SPL at individual frequencies. DPOAEs were considered present when the SNR at all individual frequencies was at least 3 dB. Present emission and noise amplitudes were averaged into half-octave frequency bands with center frequencies 1.0 kHz, 1.5 kHz, 2.0 kHz, 3.0 kHz, 4.0 kHz, 6.0 kHz, and 8.0 kHz. If DPOAEs were absent at all frequencies within a given half-octave band, emission amplitudes, and noise amplitudes were considered missing in that frequency band.

Data analysis

Statistical analysis was performed using SPSS version 22 (IBM Corp., New York, USA). Subjects were categorized in groups with low, intermediate, and high recreational noise exposure based on either their weekly or their lifetime equivalent noise exposure. Hearing thresholds, TEOAE amplitudes, and DPOAE amplitudes were measured to indicate hearing status. To evaluate whether there were significant mean differences in hearing status between noise exposure groups, one-way analysis of variance (ANOVA) was used.

It was hypothesized that young adults with high recreational noise exposure had more deteriorated hearing than those with low or intermediate recreational noise exposure. Therefore, when the significance level was reached ($P < 0.05$), *post hoc* least significant difference (LSD) with Bonferroni correction was performed between the groups of interest i.e., low versus high, and intermediate versus high recreational noise exposure.

Results

Noise-induced threshold shift (NITS)

A NITS using the criteria of Niskar *et al.*, 2001^[30] was present in 7.36% of the subjects, with maximum hearing thresholds exceeding 20 dB hearing level (HL) in half of these cases. The highest threshold was 30 dB HL in one subject. These maximum hearing thresholds were in the majority of subjects present at 6 kHz (83.3%), but also at 4.0 kHz (16.7%). The mean hearing thresholds for the subjects with and without a NITS are shown in Figure 1.

Hearing-related symptoms

In Table 1, the percentage of self-reported symptoms after recreational noise exposure is given. Temporary tinnitus occurred in 85.9% of the subjects after noise exposure. The majority of the subjects (34.4%) reported to having seldom experienced temporary hearing loss after noise exposure, followed by 32.5% who sometimes reported having temporary hearing loss.

Recreational noise exposure

In Table 2, an overview of the percentage of adolescents' attendance, time spent per week and number of years, and self-estimated median loudness for all leisure-time activities are given. The highest percentage of attendance was found for visiting nightclubs or pubs (96%), watching movies or plays (88%), and listening to PMPs through headphones (86%). The activities engaged in the most frequently per week on average were listening to a home stereo or radio through speakers (9.04 h), visiting nightclubs or pubs (5.91 h), and practicing a music instrument (3.65 h). Listening to a home stereo or radio amounted to the highest number of years on average (10.63 years), followed by watching movies or plays (9.01 years), and attending sport events (7.71 years). The loudest activity, at which one must shout over a near distance, was attending musical concerts or festivals. Four activities were evaluated as sound levels at which one must shout over 1 m, whereas the others were referred to as sound levels of a loud conversation. Furthermore, the loudness of concerts and festivals was rated as too loud by 66.9% of the participating subjects; 88.6% of the subjects visiting nightclubs assessed the sound levels

as too loud, whereas this proportion was 35.9% for visiting pubs. Finally, also reflected in Table 2 are the weekly and lifetime equivalent noise exposure values for all activities. It was found that the highest equivalent SPLs were calculated for the activities visiting nightclubs or pubs, attending concerts or festivals, and playing in a band or orchestra.

The average weekly and lifetime equivalent noise exposure for all activities was 70.09 dBA (SD 7.99 dBA, range 51.48-86.99 dBA) and 77.51 dBA (SD 7.72 dBA, range 58.28-94.92 dBA), respectively. The $L_{Aeq,w,all}$ exceeded the highest threshold for action (85 dBA) stated in the European Directive by 3.1% of the subjects, whereas the lowest threshold for action (80 dBA) was exceeded by 11.7% of the subjects.^[68] Of the subjects, 31.9% exceeded the more stringent exposure level of 75 dBA [Figure 2].

For $L_{Aeq,w,all}$, the lowest group ranged 51.48-64.33 dBA, the intermediate group 64.34-76.32 dBA and the highest group 76.33-86.99 dBA. For $L_{Aeq,l,all}$, the lowest, intermediate, and highest groups ranged 58.28-71.87 dBA, 71.88-83.11 dBA, and 83.12-94.92 dBA, respectively.

Table 1: Percentage of self-reported hearing symptoms after noise exposure (n = 163)

Symptom	Always (%)	Often (%)	Sometimes (%)	Seldom (%)	Never (%)
Temporary tinnitus	5.5	23.3	41.7	15.3	14.1
Temporary hearing loss	0.6	5.5	32.5	34.4	27.0
Ear pain	0.0	3.1	10.5	28.4	58.0
Dullness	0.0	6.8	29.6	27.8	35.8

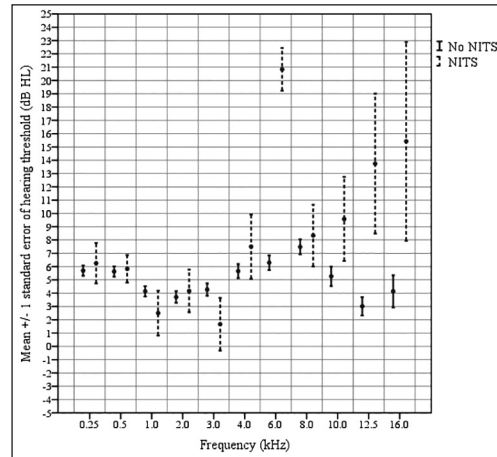


Figure 1: Mean ± one standard error of hearing thresholds for subjects with (dashed line) and without NITS (solid line)

Table 2: Percentage of subjects' attendance (n = 163), mean hours spent per week and mean number of years participating at each leisure-time activity, as well as the median loudness and mean A-weighted equivalent SPLs in dBA ($L_{Aeq,w}$: Weekly noise exposure; $L_{Aeq,l}$: Lifetime noise exposure): The standard deviation is given between brackets

Activity	Attendance (%)	Time spent		Loudness	$L_{Aeq,w}$	$L_{Aeq,l}$
		Per week	Years			
Visiting nightclubs or pubs	96	5.91 (4.65)	5.70 (2.59)	Shout over 1 m	72.64 (10.71)	79.76 (10.58)
Watching movies or plays	88	0.92 (2.10)	9.01 (3.60)	Loud conversation	54.91 (8.69)	64.07 (8.22)
Listening to a PMP through headphones	86	3.21 (3.30)	5.36 (2.79)	Loud conversation	56.42 (10.38)	62.99 (11.27)
Listening to a home stereo or radio	76	9.04 (9.96)	10.63 (5.19)	Loud conversation	58.56 (8.87)	68.19 (9.16)
Attending musical concerts or festivals	69	0.85 (0.84)	5.27 (3.37)	Shout over near distance	67.68 (9.58)	74.27 (9.80)
Attending sport events	53	3.09 (2.56)	7.71 (4.31)	Loud conversation	55.40 (8.34)	63.36 (9.37)
Practicing a musical instrument	49	3.65 (2.49)	7.45 (3.74)	Loud conversation	58.23 (10.04)	66.25 (11.50)
Playing in a band or orchestra	26	2.27 (1.19)	5.31 (3.38)	Shout over 1 m	67.65 (10.91)	74.06 (11.48)
Other noisy leisure-time activities	18	3.19 (2.98)	7.25 (4.63)	Shout over 1 m	65.07 (10.72)	72.45 (10.66)
Using noisy tools	13	0.97 (1.29)	4.21 (3.32)	Shout over 1 m	63.80 (12.61)	69.12 (12.05)
Watching television through headphones	7	2.72 (2.65)	6.00 (4.96)	Loud conversation	53.89 (6.52)	60.74 (8.32)

Hearing assessment

One-way ANOVA with *post hoc* LSD test was performed to evaluate mean differences in hearing between subjects with low versus high, and intermediate versus high recreational noise exposure. First, with regard to the weekly equivalent noise exposure for all activities, there were no significant differences in hearing thresholds, TEOAE amplitudes, and DPOAE amplitudes between groups with different noise exposure. Second, no significant differences were found between groups with low, intermediate or high lifetime equivalent noise exposure for all activities with regard to pure-tone audiometry at all tested frequencies [Figure 3]. Further, there were no significant differences at all tested frequencies in TEOAE amplitudes [Figure 4], nor for DPOAE amplitudes [Figure 5] between the three lifetime-equivalent noise exposures for all activity groups.

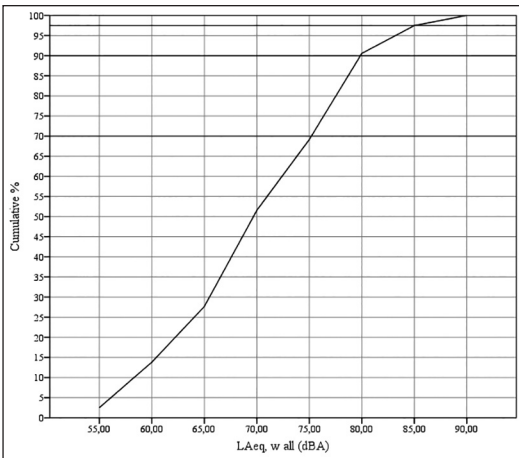


Figure 2: Cumulative distribution (%) of weekly equivalent noise exposure for all activities (dBA)

Discussion

Young people expose themselves to loud music in a lot of their daily activities, individually using their PMPs, as well as in groups in discotheques, nightclubs, concerts, festivals etc. A majority of studies have focused on the role of PMPs in the development of NIHL. However, no significant hearing impairment was seen between PMP users and non-PMP users,^[69] or between subjects with low, medium, and high usage of PMPs.^[70] In contrast, significant poorer hearing thresholds were found in subjects with higher PMPs listening time (>7 h/week vs 2-7 h/week or control)^[54] or in PMP users versus non-users.^[36,71] Further, a decline in TEOAEs was found between subjects using PMPs less than 1 h per week and those using PMPs more intensively.^[52] Significant differences in hearing thresholds were seen between a group of PMP users and controls, but no significant differences could be established between the subgroups of PMP users based on the

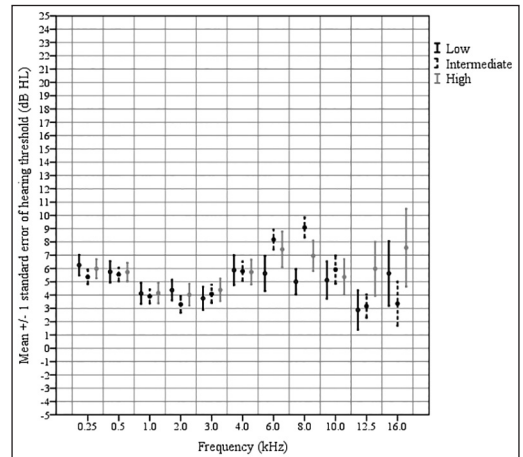


Figure 3: Hearing thresholds (mean ± one standard error) for subjects categorized in groups with low, intermediate, and high lifetime equivalent noise exposure for all activities

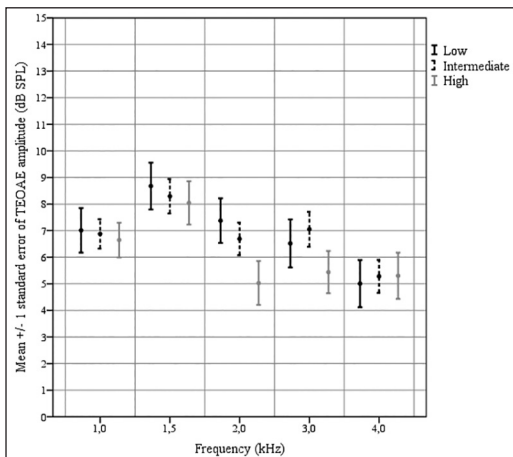


Figure 4: TEOAE amplitudes (mean ± one standard error) between groups with different lifetime equivalent noise exposure for all activities

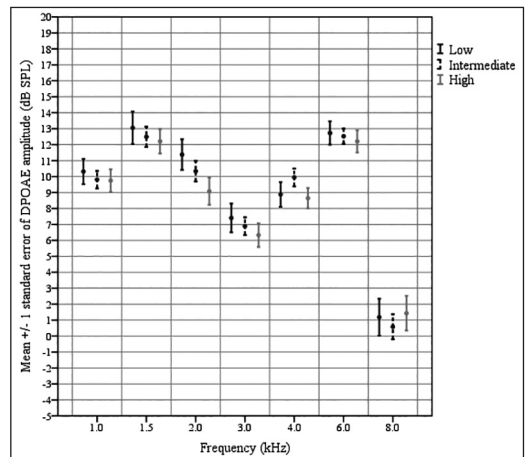


Figure 5: DPOAE amplitudes (mean ± one standard error) for groups with low, intermediate, and high lifetime equivalent noise exposure for all activities

duration of use in years.^[53] Lastly, deteriorated TEOAEs and DPOAEs were found with longer duration of PMP listening time in years, as well as in hours per week.^[72] Thus, although these studies might indicate that more extensive use of PMPs lead to hearing damage, the use of PMPs was exclusively evaluated in hours per week,^[52,54] or duration of use in years.^[53] However, both parameters should be studied dependent of each other. Further, it must be emphasized that some studies did not consider other sources of leisure-time exposure,^[52,53] which might confound their results.

So, although the current popularity of PMPs is certainly a cause for concern, there are other sources of recreational noise exposure, which are overshadowed by the popularity of PMPs. Meyer-Bisch (1996) found a significant reduction in hearing thresholds in subjects attending concerts at least once a month compared to the control group.^[54] Further, the high sound levels in nightclubs and discotheques^[10] could be more dangerous than with using PMPs.^[14] In the current study, more subjects participated at the activity visiting nightclubs or pubs, and the average time spent per week as well as the number of years was higher for this activity compared to PMPs. Furthermore, the activities with the highest A-weighted equivalent SPLs were visiting nightclubs or pubs, attending musical concerts or festivals, and playing in a band or orchestra, while listening to PMPs contributed less to the weekly exposure levels, which is consistent with previous results.^[73,74]

In the present study, the results of the audiological test battery were not statistically significant between subjects with self-reported low, intermediate, and high cumulative recreational noise exposures. There could be several possible explanations.

First, the retrospective estimation of recreational noise exposure in hours per week or month, number of years, and subjective loudness by the subjects might have led to errors in the calculation of A-weighted weekly and lifetime equivalent noise exposure values. Nevertheless, young adults are able to estimate the loudness of events reasonably well.^[75] Further, using the loudness to calculate the A-weighted equivalent SPLs induces a generalization regarding the type of noise.^[64,74] However, these levels provide a relative ranking of subjects according to their recreational noise exposure. Nevertheless, the weekly equivalent noise exposure level exceeded the highest and lowest thresholds for action as stated in the European Directive in 11.7% and 3.1% of our subjects, respectively.^[68] Moreover, 75 dBA was exceeded by one-third of our subjects, indicating that a considerable amount of subjects expose themselves to hazardous levels of recreational noise. Yet, prudence is in order, as these damage-risk criteria are based on occupational noise exposure; it does, however, stress the importance of safety guidelines for recreational noise exposure.

Second, it is plausible that the lack of hearing deterioration could be explained by the fact that recreational noise exposure is insufficient to cause widespread hearing loss. The pattern of exposure to recreational noise could be less frequent compared to occupational noise exposure, and probably accounts for only for a small period in life, i.e., 5-10 years.^[4,47,76] Moreover, the question has been raised whether it is too soon to detect permanent effects of recent advances in technology^[77] such as PMPs. However, a decline of TEOAE amplitudes with increasing music exposure was found previously.^[78] In contrast, no significant differences in hearing were found between subjects with the greatest and lowest amounts of cumulative noise exposure.^[70] In the current study, approximately 7% of the subjects exhibited a NITS, mostly at 6 kHz. An audiometric notch at 6 kHz must be interpreted with caution because it is also noted in subjects without noise exposure^[26] and can be related to calibration errors.^[28,29,79] Nevertheless, there is a definite need for long-term assessment of the auditory system of young people in relation with recreational noise exposure.

Finally, the variation in hearing thresholds as well as in evoked OAE (EOAE) amplitude might have been too large to reveal subtle cochlear damage between groups with different recreational noise exposure, and this could have been reduced with a larger sample.

Conclusion

In conclusion, no significant differences in hearing were found between groups with different recreational noise exposure. Nevertheless, one-third of our subjects exposed themselves to hazardous noise levels, although these results must be interpreted with caution due to the generalization of the type of noise and the damage-risk criteria directly adopted from occupational noise exposure. Further, the relative contribution of listening to PMPs in the weekly and lifetime equivalent sound levels was considerable less than for the activities visiting nightclubs or pubs, attending musical concerts or festivals, and playing in a band or orchestra. A long-term assessment of the auditory function in young people is needed to evaluate the possible progression in hearing deterioration caused by recreational noise exposures. Moreover, hearing conservation campaigns for young adults should provide information and knowledge regarding noise exposure, hearing loss, and HPDs, but also focus on self-experienced symptoms such as temporary tinnitus after recreational noise exposure, which was found in 86% of our subjects. These factors increase the awareness that might lead to attitudinal and behavioral change, and thus preserve hearing in young adults.

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