Estimating Adolescent Risk for Hearing Loss Based on Data From a Large School-Based Survey

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Objectives. We estimated whether and to what extent a group of adolescents were at risk of developing permanent hearing loss as a result of voluntary exposure to high-volume music, and we assessed whether such exposure was associated with hearing-related symptoms.

Methods. In 2007, 1512 adolescents (aged 12–19 years) in Dutch secondary schools completed questionnaires about their music-listening behavior and whether they experienced hearing-related symptoms after listening to high-volume music. We used their self-reported data in conjunction with published average sound levels of music players, discotheques, and pop concerts to estimate their noise exposure, and we compared that exposure to our own ''loosened'' (i.e., less strict) version of current European safety standards for occupational noise exposure.

Results. About half of the adolescents exceeded safety standards for occupational noise exposure. About one third of the respondents exceeded safety standards solely as a result of listening to MP3 players. Hearing symptoms that occurred after using an MP3 player or going to a discotheque were associated with exposure to high-volume music.

Conclusions. Adolescents often exceeded current occupational safety standards for noise exposure, highlighting the need for specific safety standards for leisure-time noise exposure. (*Am J Public Health.* 2010;100:1095–1100. doi:10.2105/AJPH.2009.168690)

With the recent massive increase in the popularity of portable digital music players such as MP3 players, exposure to high sound levels has risen dramatically, and millions of adolescents and young adults are potentially at risk of permanent hearing loss as a result.[1–3] In addition to exposure via MP3 players, many young people are exposed to high-volume music in discotheques—where mean sound levels range from 104 to 112 decibels dBA[4]—and at pop concerts, where sound levels are even higher.[5] Combined exposures to high-volume music can have cumulative effects on hearing impairment, thus exacerbating the risk of hearing loss.[1]

Given these facts, there is a need to assess how people—especially adolescents—use MP3 players and to determine users' exposure to other high-volume sound sources.[1] However, because MP3 players have been introduced to the market only very recently, few studies have assessed exposure to potentially hazardous sound levels from MP3 players.[6] Nor have any studies reported on cumulative exposure to high-volume music from a combination of sources such as MP3 players, stereo headphones, discotheques, and pop concerts. In the absence of such data, information about adolescents' self-reported music-listening behaviors may be used in combination with information about average sound levels of MP3 players, discotheques, and pop concerts to estimate whether and to what extent today's adolescents are at risk of developing permanent hearing loss from voluntary exposure to high-volume music.

We examined (1) the extent to which adolescents' exposure to music through earphones or headphones with MP3 players or home stereos, or at discotheques and pop concerts, exceeds current occupational safety standards for noise exposure, and (2) whether exposure to levels of music noise excessive of those recommended increases hearing-related symptoms among adolescents.

We based our findings on self-reported frequency, type, and duration of exposure, and on self-reported volume-control levels, combined with average sound levels for various music sources. These data were then evaluated according to the safety standards for occupational noise exposure currently promoted by the European Union.[7]

METHODS

In 2007, 1687 adolescents (aged 12–19 years) in 68 classrooms at 15 Dutch secondary schools were invited to complete a questionnaire (under supervision, at school) about their sociodemographic information, music-listening behaviors, and the occurrence of hearing-related symptoms after listening to high-volume music (see the box on the next page). Adolescents and parents received written information about the study. Parents could refuse to allow their child's participation, and participation was voluntary and anonymous.

Because ethnic differences in music-listening behaviors have been reported,[6] the questionnaire asked about the country of birth of the participant and the country of birth of each of the participant's parents. Ethnicity was determined on the basis of mother's and father's country or countries of birth according to categories defined by Statistics Netherlands.[8] We constructed 2 ethnicity categories: Dutch or Western migrant, and non-Western migrant. Our analysis controlled for participant ethnicity.

The questionnaire asked respondents how many days per week and how long per day they listened to music with earphones on an MP3 player or on nonportable music players, and at what volume level (all averaged over the previous month). Average weekly exposure time for MP3 players and nonportable music players was estimated by multiplying days per week by hours per day. The questionnaire also asked respondents how many times over the previous year, and how long per time, they had gone to a discotheque. Average exposure time per month for discotheque visits was estimated by

Questionnaire Administered to Adolescent Participants Aged 12 to 19 Years: the Netherlands, 2007

1. Sociodemographic characteristics
   - Are you a boy or a girl?
   - What is your date of birth?
   - What level of education do you attend?
2. Music exposure
   - Do you ever listen to music?

   A. MP3 player
   - Do you ever listen to music through earphones on a portable music player (MP3 player)?
   - On average over the last month, on how many days per week did you listen to music on an MP3 player?
   - How long do you normally use your MP3 player per day? At what volume-control level do you normally listen?
   - What kind of earphone do you normally use?

   B. Stereo
   - Do you ever listen to music through earphones on a nonportable music player (for example, on a computer or a stereo installation at home)?
   - On average over the last month, on how many days per week did you listen to music on a stereo?
   - How long do you normally use your stereo per day?
   - At what volume-control level do you normally listen?
   - What kind of earphone do you normally use?

   C. Discotheque
   - Have you been to a discotheque in the last year?
   - On average over the last year, how many times per month did you go to a discotheque?

   D. Pop concert
   - During the past year, how often did you go to a pop concert?
3. Hearing symptoms
   - On average over the last month, how often did you experience hearing symptoms such as tinnitus, muffled sounds, or temporary hearing loss after listening to music through earphones?
   - After going to the discotheque, do you ever experience hearing symptoms such as tinnitus, muffled sounds, or temporary hearing loss?

multiplying the number of discotheque visits per month by average time spent per visit. The questionnaire then asked respondents how many times they had gone to a pop concert during the previous year. Average exposure time per year during pop concerts was estimated by multiplying the number of visits per year by an assumed average attendance time per concert of 2.5 hours. Finally, the questionnaire asked how often the participant experienced hearing-related symptoms after listening to music through earphones or whether the participant had ever experienced hearing-related symptoms after going to a discotheque.

Because we could not measure music-volume levels, we had to estimate volume levels per music source in order to estimate exposure to potentially hazardous music levels. Portnuff and Fligor have evaluated the output levels of several of the most popular MP3 players.[9] We used their grand-average output levels across all evaluated players—which were similar to a Dutch study's evaluations of the output levels of MP3 players and earphones[10]—to convert volume-control levels of MP3 players and stereos into decibel levels. We added 5.5 dBA to the output level when respondents reported using earbud-style earphones, and we added 2.75 dBA when they reported using both earbud-style earphones and supra-aural headphones.[1,9] On the basis of published assessments of sound levels in discotheques and at pop concerts, we assumed the decibel level in discotheques to be 100 dBA, and for pop concerts we assumed the decibel level to be 105 dBA.[11]

By current European occupational safety standards,[7] noise levels equal to or exceeding the equivalent of 80 dBA for 40 hours per week are assumed to be potentially damaging. However, in a report of the EU's Scientific Committee on Emerging and Newly Identified Health Risks, it is assumed that listening for 1 hour a day to a sound level of more than 89 dBA is potentially damaging.[1] Because sound pressure levels are measured on a logarithmic scale, they cannot be added or averaged arithmetically; adding 2 sounds of equal pressure levels and durations results in a total pressure level that is only 3 dBA higher than each individual sound pressure level.[12] For instance, if an exposure of 80 dBA lasting 1 hour is added to another exposure of 80 dBA lasting 1 hour, the sum is equivalent to 80 dBA lasting 2 hours, but it is also equivalent to 83 dBA lasting 1 hour. In another example, applying the principle that a doubling in level (+3 dBA) can be offset by halving the exposure duration,[13,14] it can be calculated that listening to a music level of 89 dBA for 7 hours per week is equal to listening to a music level of 80 dBA for 56 hours per week. Therefore, we chose to use a loosened criterion of 56 hours per week instead of the more stringent safety standard of 40 hours per week, because our revised criterion still implies excessive levels of noise exposure while adding time to account for the fact that music listening is not restricted to working days (i.e., 16 hours are added for the weekend).

To estimate a weekly music dose on the basis of reported exposure times and estimated decibel levels, we first calculated permissible exposure limits (PELs) for the estimated dBA levels of each participant per music source, using the equation $PEL_{(week)} = 56/2^{(L-80)/3}$, where L represents the estimated dBA level.[13] Second, each respondent's actual exposure time per music source was divided by the permissible exposure limit to compute his or her estimated weekly music dose per music source.[13] Third, the estimated doses per music source were summed to calculate an estimated total weekly music dose for all music sources combined.[13]

TABLE 1—Characteristics and Symptoms of Adolescent Participants Aged 12 to 19 Years (N = 1512): The Netherlands, 2007

	Mean (SD) or No. (%)
Mean age, y	14.7 (1.21)
Male	764 (50.5)
Secondary school type	
Practical prevocational education	279 (18.5)
Theoretical prevocational education	472 (31.2)
Senior general secondary education	388 (25.6)
Preuniversity education	373 (24.7)
Dutch or Western migrant ethnicity	1306 (86.4)
Music exposure	
Listens to music (in general)	1500 (99.2)
Music through earphones	1410 (93.3)
Portable music players (MP3 players)	1360 (89.9)
Nonportable music players (home stereos)	718 (47.5)
Discotheque visits (prior year)	1086 (71.8)
Pop concert visits (prior year)	649 (42.9)
Hearing symptoms	
At least once in the prior month after listening to music through earphones	453 (30.0)
At least once in the prior year after going to a discotheque	888 (58.7)

Some adolescents did not complete the items on discotheques (n = 51) or pop concerts (n = 108); to calculate an estimated minimal total weekly dose for all adolescents, a dose that was missing for a certain source was assumed to be 0.

To evaluate potential risk behavior, we first used the loosened safety standard as a basis for dichotomizing participants into those who were estimated to not be exposed to potentially hazardous music levels (dose < 1) and those who were (dose ≥ 1).[13] As an additional quantification of the severity of the risk, we applied 5 sound-level categories that estimated whether respondents were exposed (by each music source and by all music sources combined) to a certain sound level for 56 hours per week (< 80 dBA, 80–84.99 dBA, 85–89.99 dBA, 90–99.99 dBA, and ≥ 100 dBA).

Cross-sectional statistical analyses were performed using SPSS version 15 (SPSS, Inc, Chicago, IL). Frequency tables were used to calculate estimates of reported exposures to potentially hazardous music levels per source of music. Multivariate odds ratios (ORs) and 95% confidence intervals (CIs) were calculated with multiple multilevel logistic regression analyses to explore the association between the estimated exposure to high volume levels and reported hearing-related symptoms after exposure (corrected for age, gender, school type, and ethnicity). We used the NLMIXED procedure with the Adaptive Gaussian Quadrature integration method in SAS version 9.1.3 (SAS Institute, Cary, NC) to account for any clustering within school classes.

RESULTS

We presented the questionnaire to 68 secondary school classrooms that comprised 1687 adolescents at full enrollment, but 165 students were not present in the classrooms at the time of data collection because of illness, visiting a doctor or nurse, participating in other school obligations, or unknown reasons. Also, 6 students who were present did

TABLE 2—Exposure to Potentially Hazardous Music Levels Among Adolescents Aged 12 to 19 Years, by Source of Music: The Netherlands, 2007

		Music Through Earphones		
	All Sources (N = 1512), No. (%)	Portable Music Players,[a] No. (%)	Nonportable Music Players,[b] No. (%)	Discotheques and Pop Concerts,[c] No. (%)
Equivalent sound level for 56 h/wk, dBA				
≥ 80	823 (54.4)	487 (32.2)	136 (9.0)	584 (40.1)
80–84.99	253 (16.7)	127 (8.4)	52 (3.4)	359 (24.7)
85–89.99	260 (17.2)	115 (7.6)	21 (1.4)	166 (11.4)
90–99.99	217 (14.4)	162 (10.7)	55 (3.7)	59 (4.0)
≥ 100	93 (6.2)	83 (5.5)	8 (0.5)	0 (0.0)

Note. dBA = decibels. Current EU safety standards specify that music volume levels of at least 80 dBA for 40 hours per week are potentially damaging. However, a report of the EU's Scientific Committee on Emerging and Newly Identified Health Risks asserts that listening to a sound level of more than 89 dBA for 1 hour per day (i.e., 7 hours per week) is potentially damaging. The noise exposure of listening to 89 dBA for 7 hours per week is equal to that of listening to 80 dBA for 56 hours per week. Thus, we used a loosened minimum safety standard of 80 dBA for 56 hours per week, to account for weekend listening.

[a]MP3 players; the sample size was n = 1510 because no weekly dose could be calculated for 2 participants because of missing data on exposure time.

[b]Home stereos; the sample size was n = 1505 because no weekly dose could be calculated for 7 participants because of missing data on exposure time.

[c]The sample size was n = 1457 because no weekly dose could be calculated for 55 participants because of missing data on exposure time.

TABLE 3—Association Between Self-Reported Hearing-Related Symptoms and Estimated Exposure to Music at Potentially Hazardous Levels Among Adolescents Aged 12 to 19 Years (N = 1512), by Source of Music: The Netherlands, 2007

	Hearing-Related Symptoms at Least Once in the Prior Month After Listening to Music Through Earphones[a,b]		Hearing-Related Symptoms at Least Once in the Prior Year After Attending a Discotheque[c]	
	%	OR (95% CI)	%	OR (95% CI)
Total study population	30.0		61.2	
Equivalent sound level for 56 h/wk, dBA				
<80 (Ref)	24.5	1.00	47.7	1.00
80–84.99	34.4	1.60 (1.05, 2.41)	87.4	8.21 (5.66, 11.90)
85–89.99	37.1	1.78 (1.20, 2.66)	80.0	4.53 (2.77, 7.40)
≥90	45.2	2.42 (1.79, 3.29)	70.0	3.30 (1.66, 6.56)

Note. CI = confidence interval; dBA = decibels; OR = odds ratio. Current EU safety standards specify that music volume levels of at least 80 dBA for 40 hours per week are potentially damaging. However, a report of the EU's Scientific Committee on Emerging and Newly Identified Health Risks asserts that listening to a sound level of more than 89 dBA for 1 hour per day (i.e., 7 hours per week) is potentially damaging. The noise exposure of listening to 89 dBA for 7 hours per week is equal to that of listening to 80 dBA for 56 hours per week. Thus, we used a loosened minimum safety standard of 80 dBA for 56 hours per week, to account for weekend listening. Associations were calculated as multilevel multivariate ORs that accounted for clustering within school classes and that were controlled for age, gender, school type, and ethnicity.

[a]Music from MP3 players and nonportable music players (home stereos) combined.

[b]The sample size was n = 1502 because 10 participants had missing data on items necessary for the analysis (exposure time, age, ethnicity, or experience of hearing-related symptoms).

[c]The sample size was n = 1427 because 85 participants had missing data on items necessary for the analysis (exposure time, age, ethnicity, or experience of hearing-related symptoms).

not complete the questionnaire, resulting in a total of 1516 questionnaires, for a response rate of 89.9%. We excluded 4 more questionnaires because of incomplete data; thus, 1512 questionnaires were used in the analyses. Participants' ages ranged from 12 to 19 years (mean=14.7; SD=1.21). Fifty percent were male, and 49.7% were attending prevocational classes. The sociodemographic characteristics of the participants reflected those of adolescents in the general Dutch population.[8] Table 1 gives an overview of the characteristics of the study population.

On the basis of the data, literature, and estimating methods described in the Methods section, we estimated that 54.4% of the study population exceeded the revised safety threshold for all sources of music combined; with regard to music from MP3 players alone, 32.2% exceeded the threshold. We estimated that 9.0% of participants exceeded the safety standard while listening to music through earphones on nonportable music players, and 40.1% exceeded the safety standard while attending discotheques or pop concerts (Table 2). We estimated that more than 6% of participants exceeded a sound level equivalent to 100 dBA for all sources of music combined; with regard to MP3 players alone, that figure was 5.5%. Only 0.5% of respondents were estimated to have exceeded a sound level equivalent to 100 dBA while listening to music through earphones on nonportable music players, and none exceeded 100 dBA while attending discotheques or pop concerts (Table 2).

Compared with adolescents not exposed to potentially hazardous music levels, those exposed to sound levels equivalent to at least 90 dBA had a higher prevalence of having experienced hearing-related symptoms at least once in the prior month after listening to music through earphones (OR=2.42; 95% CI=1.79, 3.29) and at least once in the prior year after going to a discotheque (OR=3.30; 95% CI=1.66, 6.56; Table 3).

DISCUSSION

MP3 players have been introduced to the market only very recently; thus, our study is one of the first to assess the use of such players. It provides a preliminary insight into adolescents' exposure to potentially hazardous music levels from MP3 players and their cumulative exposure to high-volume music from a combination of sources such as earphones on MP3 players and other music players, as well as at discotheques and live pop concerts. We estimated that by listening to high-volume music during leisure time, about half of the 1512 adolescents in this large, representative study exceeded a loosened European safety threshold for occupational noise exposure.[7] This estimate was based on self-reported music listening behaviors and reported average sound levels of music players, in discotheques, and at pop concerts.[9–11]

The EU's Scientific Committee on Emerging and Newly Identified Health Risks has estimated that approximately 5% to 10% of those who listen to MP3 players are at risk of developing permanent hearing loss after 5 or more years because of exposure to music for 1 hour a day (7 hours per week) at sound levels exceeding 89 dBA.[1] However, our findings show that this estimation may be too low for adolescents: we estimated that 32.2% of our participants might listen to music on MP3 players for 1 hour a day at sound levels exceeding 89 dBA.

There were significant associations between estimated exposure to high-volume music and the occurrence of hearing-related symptoms. In accordance with previous research, between 30.0% and 61.2% of participants reported temporary hearing-related symptoms after exposure to music from MP3 players and at discotheques.[5,15] Remarkably, for participants who did not listen to music levels exceeding 89 dBA for at least 1 hour a day, a quarter of them still experienced hearing-related

symptoms after listening to music on an MP3 player, and about half of them said this was the case after visiting a discotheque. This may reflect the fact that exposure to very high-volume levels of short duration can also produce such hearing-related symptoms and that individual susceptibility to the damaging effects of loud sounds is variable.[16]

This study has several limitations, one of which was the use of a convenience sample of adolescents attending 15 Dutch secondary schools; however, the characteristics of the study group reflected those of the general population of Dutch adolescents. Also, we have no information about the music-listening behaviors of nonparticipants in the study. With regard to selective nonresponse, our nonparticipation rate was only 10.1%, but this may have affected the results. In addition, significantly fewer adolescents who attended classes at the lowest educational level (practical prevocational education) completed all questions on discotheque and pop concert visits, compared with adolescents who attended classes at the higher educational levels (theoretical prevocational education, senior general secondary education, preuniversity education). Because adolescents attending schools with a lower educational level reported relatively more exposure to potentially hazardous music levels, this could mean that our estimations for visits to discotheques and pop concerts were too conservative.

The data used in our study were cross-sectional and self-reported. Because no studies are available on the reliability and validity of self-reports, there is a risk of both overreporting and underreporting.[17] However, when little is known about a subject, this kind of study is a suitable first step because it offers rapid preliminary and exploratory results and is suitable for rapid assessment of risk groups in a population.[18]

We did not measure actual volume levels to which the adolescents were exposed, but we based our estimates on conservative reports of average decibel levels.[9–11] We did not take into account other potentially hazardous sounds to which the adolescents in our study were exposed, such as music through loudspeakers (88.0%); noise created by their own activities, such as playing their own music (21.5%); noise to which they were exposed when riding mopeds or scooters (27.1%); or noise to which they were exposed when using firecrackers (60.8%). Exposure to these sound sources further increases the risk of hearing loss.

In the absence of safety standards for leisure-time sound exposure, we relied on loosened occupational safety standards. However, given the fact that occupational safety standards are based on a combination of exposure level and duration, the World Health Organization and the Scientific Committee on Emerging and Newly Identified Health Risks have proposed that such a general model should be applied to other situations where sound can have a detrimental effect, such as listening to MP3 players.[1,12]

Despite the scarcity of evidence for an association between hearing loss and exposure to high-volume music, the Scientific Committee on Emerging and Newly Identified Health Risks asserts that prolonged exposure to high-volume music (including high-volume music from MP3 players) represents a substantial health risk.[1] Our alarming finding—that about half of our study population was estimated to have exceeded loosened occupational safety standards—urgently needs to be confirmed by future studies applying elaborate exposure measurements in varied samples of adolescents. Furthermore, we recommend that longitudinal studies be conducted among the current "MP3 generation" to assess current music-listening behaviors and the health consequences of such behaviors. Such studies would also contribute to the development of safety standards for leisure-time noise exposure—which, if these findings are confirmed, are essential.

In the meantime, we recommend that medical practitioners start alerting parents, young people, and society at large to the need for preventive hearing health care. Practitioners should also help promote hearing conservation by providing health authorities with data on any possible connection between MP3 player use or participation in other music activities and a diagnosed noise-induced hearing loss. ■

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Contributors

I. Vogel assisted with study design, data collection, analysis and interpretation of data, and writing the article. H. Verschuure provided critical support throughout the study and assisted with analysis of data and writing the article. C.P.B. van der Ploeg and J. Brug assisted with conceptualization and design of the study protocol and writing the article. H. Raat conceptualized the study, developed and guided the study design, and assisted with design of the study protocol and writing the article.

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Human Participant Protection

This study was approved by the medical ethics committee of Erasmus MC, University Medical Center Rotterdam.

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