Pure tone hearing thresholds and leisure noise: Is there a relationship?

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Abstract

This paper reports on the examination of the relationship between self-reported historical noise exposure during leisure activities and audiological indicators: Measured hearing threshold levels (HTLs) and otoacoustic emissions (OAEs). The research was conducted by a cross-sectional survey of 1,432 individuals whose ages ranged from 11 years to 35 years. Methodology included a comprehensive audiometric assessment including otoscopy, pure tone audiometry (PTA) (air- and bone-conduction), OAEs, and tympanometry. A comprehensive questionnaire gathered information on demographics, hearing health status, and participation in work, nonwork, and leisure activities. Using the history of work, nonwork, and leisure noise exposure, a cumulative lifetime noise exposure was estimated. No correlation was found between cumulative lifetime noise exposure and audiometric PTA or OAE parameters.

Keywords: Hearing health, leisure noise, noise exposure, otoacoustic emissions (OAEs), pure tone threshold shift

Introduction

Media and scientific publications have alluded to an increased rate of pure tone hearing loss due to increased noise exposure from leisure activities, particularly those activities involving loud music. Several studies have reported significant hearing threshold shifts in young populations that were attributed to excessive noise exposure from the increasing participation in high noise leisure activities.[1-5] Other published work casts doubt on this assumption.[6-8] A recent comprehensive review of the literature in this area concluded that commentary to date has been "arguably more speculative than evidenced-based" and that further clearer, unambiguous information is required[9] (page 501).

There is no doubt that long-term exposure to loud noise or sound will cause a noise injury (NI) or hearing loss (HL) (i.e., a pure tone threshold shift). Given sufficient exposure, a significant hearing impairment (HI) may occur.[10] Three important factors contribute to noise exposure: The "average loudness" A-weighted equivalent level (L_{Aeq}) over the duration of the event; the time period of the event itself; and the number of events in total over the lifetime.

When considering nonwork and/or leisure noise, it is important to recognize that with the change in lifestyle there is a change in leisure activities. The exposure to noise from particular activities may intensify and then diminish on progression from adolescence to adulthood. For example, it is more typical to find younger adults (those in their mid-20s) attending dance clubs than people from older age groups (those in their mid-40s). As an individual ages, his/her leisure profile will change and accordingly his/her noise exposure profile also changes.[11]

In the context of concerns of a possible sharp increase in the incidence of pure tone hearing loss in younger people, the National Acoustic Laboratories (NAL) instituted the project "Prevalence of hearing loss and its relationship to leisure sound exposure" financed by the Office of Hearing Services under its Hearing Loss Prevention Program[12] REI 244/0708. The data presented here is a subset of the larger study,

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This study set out to test the hypothesis: "Does the perceived increase in leisure noise exposure have a detrimental effect on the hearing health of young Australians, as evidenced by hearing threshold levels?"

Methods

Subjects

A representative sample of the population in New South Wales, Australia aged 11-35 years was recruited from various organizations including high schools, universities, tertiary and further education colleges, and a variety of workplaces including the government sector and private industries. No exclusion was made, apart from the requirement of the target age range. Importantly, information on current hearing health status or noise exposure history was not a preparticipation requirement.

Participants were asked to complete a comprehensive hearing health, attitude, and behavior survey with particular emphasis on leisure participation that may have involved significant noise. This included but was not limited to attendance at dance clubs, concerts, loud music events, personal use of stereo, phone, playing a musical instrument, participation in a band or orchestra, firearm use, and motor sports. This survey was completed either on paper or online, usually prior to attendance at the assessment appointment where comprehensive audiometric testing was carried out. Some further questions in relation to current hearing health status, recent noise exposure, and knowledge of hearing health principles were also asked during the appointment.

A total number of 1,432 individuals provided sufficient information to be able to contribute to this study. The full details of the thresholds of this group have been published previously.[13]

Audiometric testing

Audiometric testing was carried out on location as opposed to requesting individuals to attend one central location. A modest donation per participant was made to the charity of choice of each participating organization. No individual incentives were offered. Organizations were recruited from a diverse range of areas including cities, greater metropolitan areas, and rural locations in an attempt to include participants from a wide range of socioeconomic and demographic backgrounds.

Audiometric tests included air-conduction audiometry (500 Hz, 1,000 Hz, 2,000 Hz, 4,000 Hz, 6,000 Hz, and 8,000 Hz) and bone-conduction audiometry (500 Hz, 1,000 Hz, 2,000 Hz, and 4,000 Hz) if air conduction thresholds were worse than 15 dB (masked if required). The audiometric test conditions met the requirements of international standards for measuring down to a minimum 0 dB hearing threshold level (HTL) with an uncertainty of +5 dB.[14] This was managed by choosing the quietest, appropriate available location at the test site and using insert earphones covered by a noise excluding headset,[15] thus ensuring that the strict requirements for maximum permissible ambient sound pressure levels as stipulated by the International Organization for Standardization (ISO) 8253-1[14] were met. Ambient noise conditions were sampled throughout the test session and any results obtained during noncompliant conditions were excluded from the analysis.

Prior to audiometric testing, an otoscopic examination was undertaken to exclude occluded ear canals or any other irregularity. All tests were carried out by appropriately qualified, professional audiologists. A comprehensive description of all the audiometric tests that were carried out and the detailed hearing threshold levels determined are presented in detail in a specific report on this aspect of the study.[13]

Both distortion-product otoacoustic emission (DPOAE) and transient-evoked otoacoustic emission (TEOAE) were measured. For DPOAEs, amplitude (two protocols) and signal-to-noise (SNR) parameters were measured from 1.5-8 kHz, for TEOAEs, reproducibility, amplitude, and SNR were measured from 1-4 kHz.

Estimation of lifetime noise exposure

NAL has investigated noise exposure in the Australian community over many years and has developed specific research tools to gather information on the historic noise exposure of individuals and groups.[16] These measures provide data that can be used to estimate cumulative lifetime noise exposure, by extending the techniques described in ISO 1999 for calculating the daily A-weighted sound exposure, $E_{A,8h}$.[10] The ISO technique is extended in a straightforward way by summing multiple exposures from multiple sources over an extended period to include all significant exposures over the lifetime. For simplicity, in the current report, cumulative noise exposure is presented in the units of Pascal squared hour (Pa^2h) rather than Pascal squared second (Pa^2s) as used for $E_{A,8h}$. This procedure provides the value of an 8-h continuous A-weighted noise exposure of 85 dB being 1.01 Pa^2h rather than 3.64 kPa^2s.

The value 1.01 Pa^2h represents a significant value as it is frequently the defined action level or Exposure Standard for exposure to continuous workplace noise in many Workplace Health and Safety jurisdictions around the world.[17] As such, it conveniently represents a recognizable indication of the relative risk of hearing loss or noise injury for the individual exposed to noise. Furthermore, the figure of 1.01 Pa^2h represents what can be considered as an "acceptable daily exposure." While this does not represent a zero risk situation, it does represent what has been agreed as a generally acceptable risk to exposure. This concept provides the basis for the following discussions.

NAL has accumulated information on typical noise exposure during nonwork and leisure activities, particularly those considered "high risk," that are used when estimating individual noise exposure.[18] Activities are considered to be of high risk when they present a noise risk of magnitude greater than that provided by exposure to the recommended Exposure Standard of 1.01 Pa²h. From an individual's personal history, an understanding of his/her overall noise exposure profile can be readily gained and his/her cumulative life noise exposure estimated.

What is a "safe" as opposed to "acceptable" noise exposure level?

Having established what can be considered as an acceptable level of daily exposure, it is possible to propose a "safe" or "low risk" exposure level. If the acceptable risk is taken to be 1 Pa²h/day, then a negligible risk of one-tenth of this, 0.10 Pa²h, could be proposed as posing a relatively negligible risk. This is equivalent to a daily exposure, $L_{Aeq,8h}$, of 75 dB.

Data analysis and ethics

All statistical calculations were carried out using Microsoft Excel® 2010 and/or Statistica® version 10 (Dell Pty Ltd).

Ethics approval for this project was provided by the Australian Hearing Human Research Ethics committee and, with respect to work in schools, the (New South Wales) NSW Department of Education and Training - Student Engagement and Program Evaluation Bureau.

Table 1: Thresholds for all participants at measured frequencies (ears = 2,255)

Age group (years)	Sample size (ears)	Threshold at frequency (Hz) — median 500	1,000	2,000	3,000	4,000	6,000	8,000
12-13	240	10	5	5	5	5	5	5
14-15	195	5	5	5	5	5	5	5
16-17	455	10	5	5	5	5	5	5
18-19	174	5	5	5	5	5	5	5
20-21	120	5	5	5	5	5	5	5
22-23	137	5	5	5	5	5	0	5
24-25	174	5	5	5	5	5	5	5
26-27	162	5	5	5	5	5	5	5
28-29	165	5	5	5	5	5	5	5
30-31	175	5	5	5	10	5	5	5
32-33	131	5	5	5	5	5	5	5
34-35	127	10	5	5	5	5	5	5

Results

Pure tone audiometry (PTA) and hearing thresholds

The hearing thresholds for participants are summarized for 2-year age intervals in Table 1 at the measured frequencies (500 Hz, 1,000 Hz, 2,000 Hz, 3,000 Hz, 4,000 Hz, 6,000 Hz, and 8,000 Hz). A small proportion of participants (31 = 2.7%) were unable to provide measurable thresholds for both ears for reasons such as middle ear pathology and impacted cerumen. As can be seen in Table 1, the median threshold was well within what would be considered the "normal" range for clinical purposes.[13]

Table 2 presents a summary of the hearing threshold levels, at fractiles 0.1, 0.25, 0.5 (median), 0.75 and 0.9 for the left and right ears for the noise-exposed participants who reported exposure greater than 1 Pa²h (N= 1179, f= 679, m = 500) with age ranging from 11 years to 35 years. Respondents who reported less than 1.0 Pa²h either failed to complete the noise exposure survey or had such minor exposure that they were not included in this analysis. Again, the distributions of the HTLs are well within the conventional range of "normal." The compression of the range to above 0 dB is an artifact of testing only to a minimum level of 0 dB HTL and using a 5-dB test step size.[14,19]

Maximum threshold values of 60 dB and 120 dB were recorded in two instances. There were some participants who had known monaural or binaural hearing losses, as is to be expected from a random population of this size. Interestingly, the individuals with significant hearing losses generally recorded minor noise exposure histories. It is also interesting to note that extensive hearing loss was not typical among the highest noise-exposed participants who only showed thresholds of up to 35 dB (see discussion below).

Otoacoustic emissions (OAEs)

As there are no recognized or agreed normative values for OAE responses (TEOAE amplitude and SNR; DPOAE amplitude) the measured values and distributions are not directly reported here. These are presented in detail elsewhere.[20] There were no significant correlations or

Table 2: Hearing threshold distribution of the left ears and right ears for all participants who reported noise exposure greater than 1 Pa²h, N = 1,179 (f = 679, m = 500)

Fractile	Left ear: Threshold level (dB) @ frequency (Hz)							Right ear: Threshold level (dB) @ frequency (Hz)						
	500	1000	2000	3000	4000	6000	8000	500	1000	2000	3000	4000	6000	8000
0.1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0.25	5	5	5	0	0	0	0	5	5	5	5	0	0	0
0.5 (Median)	5	5	5	5	5	5	5	5	5	5	5	5	5	5
0.75	10	10	10	10	10	10	10	10	10	10	10	10	10	10
0.9	15	15	15	15	15	15	15	15	15	15	15	15	15	15

changes found between any of the commonly measured OAE parameters and cumulative lifetime noise exposures. (*viz*., for TEOAEs, amplitude and SNR@1-4 kHz; and for DPOAEs, amplitude@1.5-8 kHz).

Noise exposure

Statistically, there was no significant difference between the exposure levels reported by males and females. The mean exposure for females was 3.11 kPa^{2}h [standard deviation (SD) = 7.33] and for males was 2.90 kPa^{2}h (SD 5.27) with a P value of 0.596. The mean exposure for combined males and females was 2.99 kPa^{2}h (SD = 0.44) while the median was 0.77 kPa^{2}h.

Figure 1 presents the cumulative life noise exposure calculations as related to participant age. As can be seen in Figure 1, the vast majority of individuals are concentrated at lower exposure levels (median = 0.77 Pa^{2}h). As a reliability check, to confirm that the reported activity/noise exposure data was feasible the 10 highest exposed individuals were selected from Figure 1 for more detailed analysis.

Highest exposed individuals — Case studies

As indicated in Table 3 below the highest exposed individual, at 86.7 kPa^{2}h, was a 35-year-old female who reported having attended dance clubs from the age of 18 years to 31 years, one to three times per week, for 5-7 h per attendance, and having never worn earplugs or any other hearing protector. She also reported high use of personal stereophone and high incidence of listening to music through speakers at home, both at loud volumes. The exposure rate was calculated to be 2.5 kPa^{2}h/year. All of the data pertaining to dance clubs and listening to music provided by the individual appears reasonable, that is, within the possibilities of typical leisure participation in the time available at that age.

A detailed summary of the 10 highest noise-exposed participants, including their cumulative exposure, gender, age, exposure rate, and HTLs for the left and/or right ears, are presented in Table 3.

Discussion

Initial analyses of data were concerned with a comprehensive examination of participant hearing thresholds and/or hearing loss with respect to their cumulative lifetime noise exposure. Numerous attempts were made, using multiple regression analysis, to relate cumulative exposure to individual threshold levels and combination of threshold levels. This included using thresholds at individual frequencies and the averages of several combinations of threshold levels at selected frequencies. There were no statistically significant correlations found between lifetime cumulative noise exposure and hearing thresholds.

The information obtained from the participants indicates that there is an extremely wide variation of noise exposure across the community and that the exposure levels may be expected to produce a permanent threshold shift (PTS) in hearing in many individuals. Cumulative exposure ranged from relatively negligible values up to a maximum of 86.7 kPa^{2}h, with an exposure rate of 2.94 kPa^{2}h per year. This is far beyond the expected occupational exposure for an equivalent

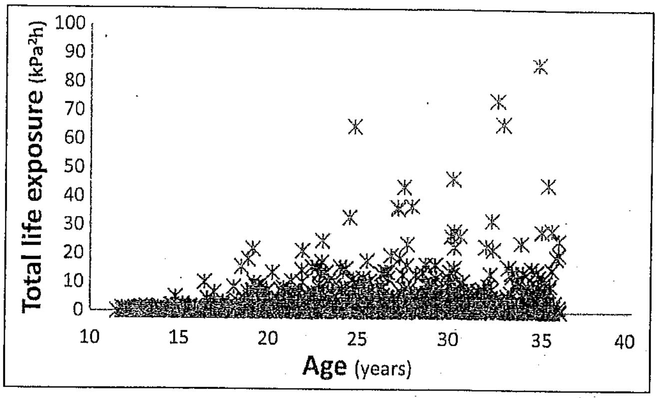

Figure 1: Cumulative life exposure related to age for all noise-exposed participants

Table 3: Details of the 10 highest noise-exposed participants including cumulative exposure, exposure rate, and left/right hearing thresholds

Cumulative exposure (Pa^{2}h)	Gender f/m	Age (Years)	Exposure rate (Pa^{2}h/year)	Measured hearing threshold levels (dB HTL)						
				500 Hz left/right	1,000 Hz left/right	2,000 Hz left/right	3,000 Hz left/right	4,000 Hz left/right	6,000 Hz left/right	8,000 Hz left/right
86,727	f	35	2,493	10/10	15/10	15/5	10/5	5/5	5/5	20/5
74,098	f	33	2,275	10/10	15/15	20/15	20/15	10/10	15/10	25/10
65,806	f	33	2,001	15/15	25/20	35/25	15/10	10/5	10/10	20/10
64,885	m	25	2,617	0/5	15/5	25/15	5/5	0/0	0/10	10/10
46,681	m	30	1,543	10/20	20/15	10/20	0/10	5/5	5/5	15/15
44,593	f	35	1,263	10/5	15/10	10/10	10/15	10/10	10/5	5/5
43,766	m	27	1,589	10/5	5/5	10/5	10/5	10/5	5/5	10/5
37,057	f	27	1,324	0/0	0/0	0/0	5/0	0/0	5/0	5/0
36,062	f	27	1,325	5/5	5/5	5/10	5/15	10/15	10/20	15/15
33,055	m	24	1,348	20*/15	10*/10	10*/15	15*/10	10*/10	10*/0	5*/0
32,017	f	32	991	5/10	5/15	5/5	5/0	5/5	5/10	5/10

*Left ear thresholds collected by earphones rather than inserts as the canal condition was unsuitable for insert use individual working in the industry if exposed to a level at the Exposure Standard of 1 Pa²h per day for 220 working days per year for 40 years, who only receives 8.8 kPa²h.

As is clearly shown from Tables 1 and 2, there is no demonstrated significant hearing loss across the sample populations, that is, there is no evidence of a shift in the noise-exposed population where it would be expected on the basis of previous reports[1-3] and ISO 1999.[10] The threshold distributions down to the 0.90 fractile level can be considered as clinically insignificant or unremarkable due to the poorest value of 15 dB across all frequencies. It should be noted that currently there are no recognized normative threshold levels published for any large scale population of less than 18 years of age. The closest applicable set of reference HTLs come from the International Standard "ISO 7029 Acoustics — Statistical distribution of hearing thresholds as a function of age" and this commences at the age of 18 years.[21] The normative levels presented in Table 1 agree well with those presented in ISO 7029, taking into consideration that in the method under discussion here the minimum HTL measured was 0 dB due to constraints of field testing.[19]

It is important to emphasize that these results do not suggest that frequent exposure to loud sound does not and will not affect hearing thresholds, particularly if the exposure occurs over the long term. Certainly this has been proven otherwise through the existence of International Standard "ISO 1999 Acoustics — Estimation of noise-induced hearing loss."[10] In interpreting these findings, it is also important to consider the evidence that individuals display over the varying susceptibility to noise exposure in terms of noise injury and hearing loss.[10,22] It may be possible that the variable characteristics of noise in leisure situations produce different outcomes when compared to the more consistent characteristics of workplace noise.[23] The range of thresholds (presented in Table 3) associated with the range of exposures for the most highly exposed participants may be indicative of varying individual susceptibility as predicted by ISO 1999.

There is a growing body of evidence showing that central auditory processing is slower, weaker, and localized differently in the noise-exposed human brain and recent research suggests that a noise-exposed individual's auditory skills are adversely affected prior to the clinical measurement of hearing loss.[24,25] This could explain the basis of the frequently made comment "I can hear OK but sometimes have trouble following conversation in background noise."

Limitations

The major limitation of this survey is that it was not a true random sample of the population under study. Participants could only be tested in locations where there was management agreement and where the testers could conveniently and reliably set up equipment for audiological testing. Mobile worksites and small workplaces were not represented.

Possibly, the greatest uncertainty arises from the method of estimating cumulative lifetime noise exposure from self-reported responses. If this is the case, it can be reasonably assumed that as all participants were in the same position there was an overall consistency in responses such that overall trends and implications were consistent.

Conclusion

These results here demonstrated that there is no evidence of change in hearing thresholds or OAEs due to noise exposure from leisure activities.

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Conflicts of interest

There are no conflicts of interest.

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