HEARING AND LEISURE NOISE

Warwick Williams

National Acoustic Laboratories
Sydney, 2109, Australia
Email: warwick.williams@nal.gov.au

Abstract

This presentation reports on the examination of the relationship between self-reported noise exposure during leisure activities and audiological indicators: including measured hearing threshold levels (HTL) and tinnitus. The research was conducted by cross sectional survey of 1432 individuals from 11 to 35 years old. Methodology included of a full audiometric assessment including otoscopy, pure tone audiometry (PTA) (air-and bone-conduction), otoacoustic emissions (OAE) and tympanometry. A comprehensive questionnaire gathered information on demographics, hearing health status and participation in work, non-work and leisure activities. Using the history of work, non-work and leisure noise exposure a cumulative life time noise exposure was estimated. No correlation was found between cumulative life time noise exposure and audiometric PTA or OAE parameters. However, tinnitus was found to frequently occur at what would be considered as low exposure levels.

1. Introduction

Media and scientific publications frequently allude to an increased rate of hearing loss through increased noise exposure during leisure activities - particularly involving loud music. Several studies have reported significant hearing threshold shifts in young populations 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].

It is accepted that long-term noise exposure 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' (L_{Aeq}) over the duration of the event; the time period of the event itself; and the number of events in total.

When considering non-work and leisure noise it must be recognised that as an individual's lifestyle changes so to do their leisure activities. The exposure to noise from particular activities will vary during progression from adolescence to adulthood. Hence as life style changes so does noise exposure. Thus as an individual ages their leisure profile changes and their noise exposure profile also changes [11]. In this context the National Acoustic Laboratories (NAL) instituted a project called "Prevalence of hearing loss and its relationship to leisure-sound exposure" financed by the Office of Hearing Services, under their Hearing Loss Prevention Program [12] REI 244/0708. The data presented here is a subset of the larger study.

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

2. Methods

2.1 Subjects

A sample of the NSW population between 11 and 35 years old was recruited from various organisations including high schools, universities, TAFE Colleges and a variety of workplaces from government and private sectors. The only criteria was to be within the target age range.

Participants completed a comprehensive hearing health, attitudes and behaviour survey with a particular emphasis on leisure participation involving significant noise. This included but was not limited to; attendance at dance clubs, concerts, loud music events; personal stereo use; playing a musical instrument; participation in a band or orchestra; firearm use; and motor sports. The survey was completed, on paper or on-line, prior to attendance at an assessment appointment for comprehensive audiometric testing. Further questions relating to current hearing health status, recent noise exposure and knowledge of hearing health principles were asked during the appointment.

A total number of 1432 (m = 42%, f = 58%) individuals provided adequate information to be able to contribute to this study. The full details of the thresholds of this group were published previously [13]. No individual incentives were offered, but a modest donation per participant was made to the charity of choice of each participating organisation. Organisations were recruited from a diverse range of areas including city, greater metropolitan and rural locations in an attempt to include participation from a wide range of socio-economic and demographic backgrounds.

2.2 Audiometric testing

Audiometric testing was carried out on-location. The audiometric test conditions met the requirements of international standards for measuring to a minimum 0 dB HTL with an uncertainty of +5 dB [14]. This was managed by choosing the quietest, appropriate available location at the test site and the use of 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 ISO 8253-1 [14] were met. Ambient noise conditions were sampled throughout the test session and any results obtained during non-compliant conditions were excluded from the analysis.

Audiometric tests included air-conduction audiometry (500, 1000, 2000, 4000, 6000 & 8000 Hz) and bone-conduction audiometry (500, 1000, 2000, 4000 Hz) if air-conduction thresholds were worse than 15 dB (masked if required). 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 audiometric tests carried out and detailed hearing threshold levels determined, are presented in detail in a specific report on this aspect of the study [12].

Both distortion product (DPOAE) and transient evoked TEOAE) were measured. For DPOAE amplitude (two protocols) and signal-to-noise ratio (SNR) parameters were measured in the range 1.5 – 4 kHz, and for TEOAE reproducibility, amplitude and SNR were measured from 1 – 4 kHz.

2.3 Estimation of life-time noise exposure

NAL has investigated noise exposure 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 used to estimate cumulative life time noise exposure, by extending the techniques described in International Standard ISO 1999 for calculating the daily A-weighted sound exposure, $E_{A,8h}$ [10]. The ISO technique is extended by summing multiple exposures, from multiple sources over an extended period. This includes all significant exposures over a life time. Cumulative noise exposure is presented in the units of Pascal squared hours (Pa^2h) rather than Pascal squared seconds (Pa^2s) as is used for $E_{A,8h}$. This procedure provides the value of an eight hour 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 the defined action level, or Exposure Standard, for exposure to continuous workplace noise in Australia and New Zealand [17]. As such it conveniently represents a recognisable indication of the relative risk of hearing loss, or noise injury, for the noise exposed individual. Furthermore, the figure of 1.01 Pa^2h represents what can be considered as an “acceptable daily exposure”. This does not represent zero risk, rather it represents what is agreed as a generally acceptable exposure risk. This concept provides the basis for the following discussions.

Accumulated information on typical noise exposure during non-work and leisure activities, particularly those considered ‘high risk’, are used when estimating individual noise exposure [18]. An activity is considered to be high risk when it presents a noise risk an order of magnitude greater than that provided by exposure to the recommended Exposure Standard of 1.01 Pa^2h.

2.4 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 Pa^2h/day then a negligible risk of one tenth of this, 0.10 Pa^2h, could be proposed as posing a relatively negligible risk. This is equivalent to a daily exposure, $L_{Aeq,8h}$, of 75 dB.

2.5 Data analysis and Ethics

All statistical calculations were carried out using Microsoft Excel® 2010 and/or Statistica® Version 10 (Dell P/L). Ethics approval was provided by the Australian Hearing Human Research Ethics committee and, with respect to work in schools, the NSW Department of Education and Training - Student Engagement and Program Evaluation Bureau.

3. Results

3.1 Pure Tone Audiometry and hearing thresholds

The hearing thresholds for participants are summarised for two year age intervals in *Table 1* at the measured frequencies (500, 1000, 2000, 3000, 4000, 6000 and 8000 Hz). A small proportion of participants (31 = 2.7%) were unable to provide measurable thresholds for both ears for reasons such middle ear pathology, impacted cerumen, etc. As can be seen in *Table 1* the median threshold was well within what would be considered the ‘normal’ range for clinical purposes [21].

Table 1. Thresholds for all participants at measured frequencies (# ears = 2255)

Age group (years)	**Sample size (ears)**	**Threshold at frequency (Hz) - median**						
		500	**1000**	**2000**	**3000**	**4000**	**6000**	**8000**
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

3.2 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 (SD = 7.33) and for males 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 related to participant age. As can be seen 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 highest 10 exposed individuals were selected from Figure 1 for more detailed analysis.

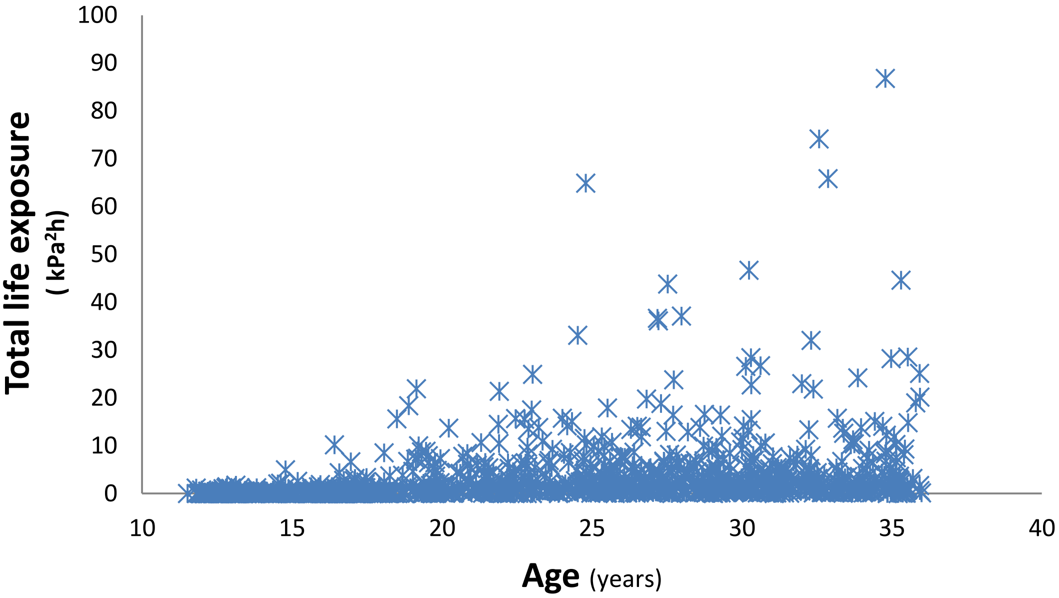

Figure 1. Total cumulative life exposure related to age for all noise exposed participants

3.3 Highest exposed individuals - case studies

A detailed summary of the highest eleven exposed participants, including their cumulative exposure, gender, age, exposure rate and HTLs for left/right ears respectively are presented in Table 2. As indicated in Table 2 the highest exposed individual, at 86.7 kPa^{2}h, was a 35 year old female who reported attending dance clubs from the age of 18 to 31 years, between one and three times per week, for 5 - 7 hours per attendance, never wearing earplugs or other hearing protectors. She also reported high personal stereo use 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/yr. All of the dance club and music listening data provided by the individual appears reasonable, that is, within the possibilities of typical leisure participation in the time available.

Table 3 presents a summary of the hearing threshold levels, at fractiles 0.1, 0.25, 0.5 (median), 0.75 and 0.9; for left and right ears; for the noise exposed participants who reported exposure greater than 1 Pa^{2}h (N = 1179, f = 679, m = 500); for age 11 to 35 years. Respondents who reported less than 1.0 Pa^{2}h 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 a testing artefact only to a minimum level of 0 dB HTL and using a 5 dB test step size [14], [19].

Maximum threshold values of 60 and 120 dB were recorded respectively in two instances. There were some participants who had known monaural or binaural hearing losses which 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 showed thresholds up to 35 dB at worst (see discussion below).

Table 2. Details of the top eleven extreme noise exposed participants including cumulative exposure, exposure rate and left/right hearing thresholds

Exposure *Pa^2h*	**Gender** *f/m*	**Age** *Years*	**Exposure rate** *Pa^2h/year*	**Measured hearing threshold levels** (dB HTL)						
				500 Hz l/r	**1000 Hz** l/r	**2000 Hz** l/r	**3000 Hz** l/r	**4000 Hz** l/r	**6000 Hz** l/r	**8000 Hz** l/r
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

Note: * Left ear thresholds collected by earphones rather than inserts as the canal condition was unsuitable for insert use

Table 3. Hearing threshold distribution, left ears and right ears, for all participants who reported noise exposure greater than 1 Pa^2h, N = 1179 (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

3.4 Otoacoustic Emissions

As there are no recognised 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 changes found between any of the commonly measured OAE parameters and cumulative life time noise exposure.

3.5 Tinnitus

There were 1,359 responses to the question "*Have you ever had tinnitus? No; Yes, sometimes; Yes, often; Yes, all the time*" of which 530 (37%) said *No* and 856 (63%) said *Yes*. In respect to frequency of experiencing tinnitus, of those who indicated they had experienced tinnitus, 751 (55.3%) said '*Yes, sometimes*', 69 (5.1%) '*Yes, often*' and 36 (2.7%) '*Yes, always present*'. These results are summarised in Table 4.

Table 4. Responses to the question 'Have you ever had tinnitus?'

"Have you ever had tinnitus?" (ie "ringing" buzzing", or other sounds in your ears")	**Number (%)**
Did not respond	61 (out of 1420)
No	530 (37%)
Yes	856 (63%)
- Yes, sometimes	- 751 (55%)
- Yes, often	- 69 (5%)
- Yes, all the time	- 36 (3%)
Total	1,359 (100%)

There is a strong relationship between the median cumulative life-time exposure and the experience of tinnitus for the four frequency reporting values of *'No'*, *'Sometimes'*, *'Often'* and *'All the time'*. This relationship, demonstrated in *Figure 2 ('No'* = 1; *'Sometimes'* = 2; *'Often'* = 3; and *'All the time'* = 4). The line of best fit for median threshold levels shows a steady growth in the increase in the experience of tinnitus with increasing cumulative exposure. The relation using the mean cumulative life exposure was similarly positive but not as good a fit. The average age of those who experienced tinnitus 'all the time' was 27.8 years (SD = 6.8). The median was 29.4 years which is consistent with the expected tendency of greater incidence of tinnitus toward older age. The youngest person who indicated tinnitus 'all the time' was a 16.5 year old male. Males outnumbered females for tinnitus 'all the time' with respective numbers of 22 to 14.

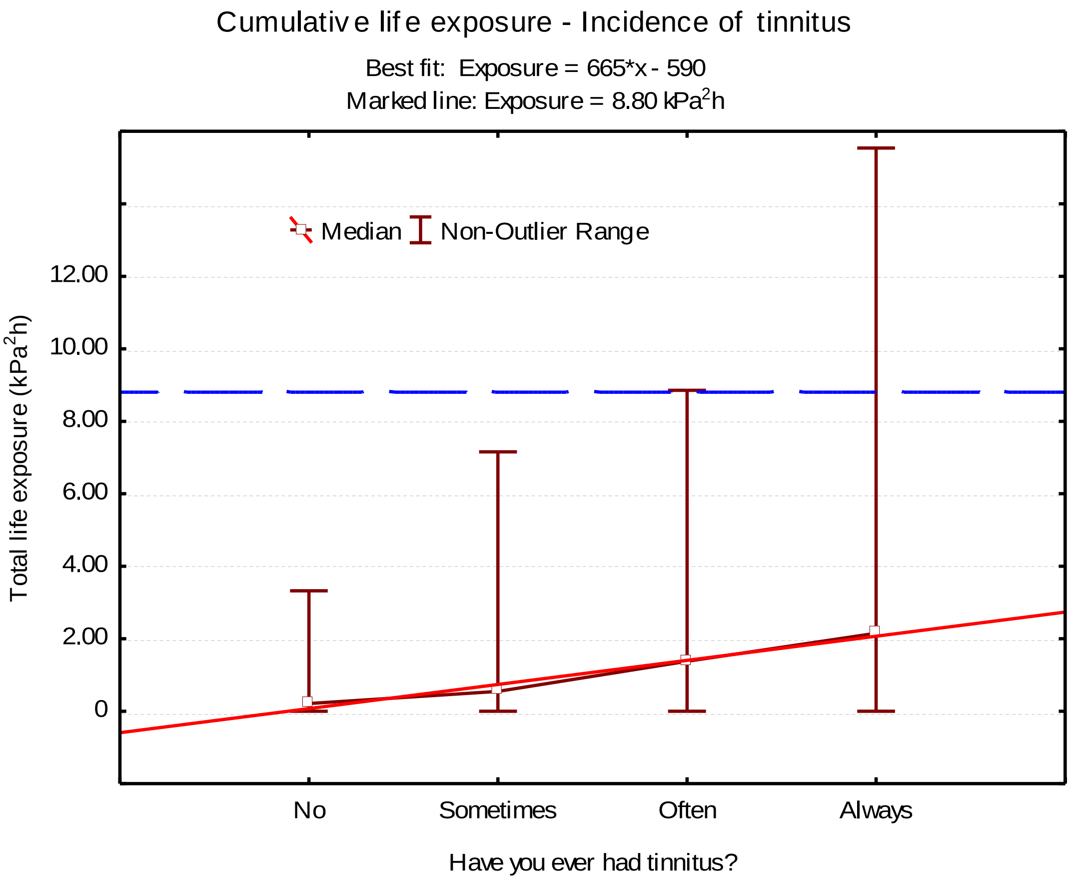

Figure 2. Graph of median cumulative life exposure (Pa^2h) in relation to experience of tinnitus and the non-outlier range of values. Line of best fit, Exposure = 665*x – 590 (Pa^2h). The line of cumulative exposure = 8.80 kPa^2h is explained in the accompanying text

As the graph of Figure 2 indicates, there is a strong relationship (R^2 = 0 .997) between experience of tinnitus and the median exposure. The relationship with mean exposure was not as good as with the median demonstrating the effects of extreme values. The mean and median values are compared in Table 5.

Table 5. Cumulative life exposure, mean and median values with respect to tinnitus

Cumulative life exposure (Pa^2h)	Have you ever had tinnitus?			
	No	**Yes, sometimes**	**Yes, often**	**Yes, all the time**
Mean (SD)	1.91 (3.87)	3.64 (7.69)	3.44 (5.08)	6.48 (13.05)
Median	0.49	1.02	1.52	2.25

4. Discussion

Noting that the aim of this study was to examine the relationship between leisure noise exposure and hearing health, the initial analyses of the data were concerned with a comprehensive examination of participant hearing thresholds and/or hearing loss with respect to their cumulative life time 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 life time cumulative noise exposure and hearing thresholds.

The information obtained from participants indicates there is an extremely wide variation of noise exposure across the community and that the exposure levels may be expected to produce a permanent hearing threshold shift (PTS) in many individuals. Cumulative exposure ranged from relatively negligible values up to a maximum of 86.7 kPa^2h with an exposure rate of 2.94 kPa^2h per year. This is, far beyond the expected occupational exposure for an equivalent individual working in industry if exposed to a level at the Exposure Standard of 1 Pa^2h per day for 220 working days per year for forty years, who only receives 8.8 kPa^2h.

As is clearly shown from Tables 1 and 3 there is no demonstrated significant hearing loss across the sampled 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], [2], [3] and ISO 1999 [10]. The threshold distributions down to the 0.90 fractile can be considered as clinically insignificant or unremarkable down to the poorest value of 15 dB across all frequencies. It should be noted that currently there are no recognised normative threshold levels published for any large scale populations younger than 18 years old. The closest applicable set of reference HTLs come from International Standard "*ISO 7029* which commence at age 18 years [20]. 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 that there is evidence that individuals display 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.

The results in the current work were closely mirrored in an earlier, on-line survey of exposure to loud leisure noise activities conducted by the National Acoustic Laboratories and the ABC, '*Sound Check Australia*' [22]. In this study individuals were asked about their participation in high-noise leisure activities and symptoms of hearing damage. Tinnitus question responses indicated experience of tinnitus at: 30% ‘never’; 37% ‘occasionally’; 18% ‘sometimes’; 4% ‘often’; and 2% ‘always’. There were 9% of survey respondents who selected the ‘unsure’ category for this question and were excluded from further analysis. If the ‘occasionally’ and ‘sometimes’ categories are combined these results closely mirror the current study. Both this study and the current, in fact, represent the same overall Australian population so close agreement is to be expected.

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

6. Conclusions

The results here demonstrated that there is no evidence of changes in hearing thresholds or otoacoustic emissions due to noise exposure from leisure activities. However, the experience of tinnitus has been clearly demonstrated to be widespread in the young adult population and there is a strong relation to cumulative noise exposure from noisy activities. Improved, personalised hearing health education messages could draw attention to the experience of tinnitus after early episodes of noise exposure, utilising this awareness as a facilitator for future personal preventative action by young adults before higher levels of noise exposure are reached.

7. Acknowledgements

I wish to thank Lyndal Carter and Mark Seeto for assistance in preparation of this presentation. I also wish to thank Denise Macoun, Jermy Pang, Jenny Rosen for valuable assistance with collection of the original data; Elizabeth Beach for comments on data analysis; and the Office of Hearing Services, Hearing Loss Prevention Program for project funding.

References

[1] Shargorodsky J, Curhan SG, Curhan GC, Eavy, R. “Change in prevalence of hearing loss in US adolescents”, *Journal of the American Medical Association*, **304**, 772–778, (2010).

[2] Cone BK, Wake M, Tobin S, Poulakis Z, Rickards FW. “Slight-mild sensorineural hearing loss in children: Audiometric, clinical, and risk factor profiles”, *Ear & Hearing*, **31**, 202–212, (2010).

[3] LePrell CG, Hensley BN, Campbell KCM, Hall JW, Guire K. “Evidence of hearing loss in a ‘normally-hearing’ college-student population”, *International Journal of Audiology*, **50**, S21–S31, (2011).

[4] Nemes J. “Teen hearing loss study goes viral, experts uncover the facts”’ *The Hearing Journal*, **64,** 19 –24, (2011).

[5] Brande V. “The teen hearing loss ‘state of emergency’”, editorial in *The Hearing Journal*, **64**: 4, (2011).

[6] Hoffman HJ, Dobie RA, Ko CW, Thermann CL, Murphy WJ. “Americans hear as well or better today compared with 40 years ago: Hearing threshold levels in the unscreened adult population of the United States, 1959-1962 and 1999-2001”, *Ear & Hearing*, **31**, 725–734, (2010).

[7] Schlauch RS, Carney E. “Are false positive rates leading to an overestimation of noise-induced hearing loss?” *J Speech, Language and Hearing Research*, **54**, 679–692, (2014).

[8] Schlauch RS. “Noise-induced hearing loss in teenagers”, *Acoustics Today*, 14–18, (2013).

[9] Carter L, Williams W, Black D & Bundy A. “The leisure-noise dilemma: hearing loss or hearsay? What does the literature tell us?”, *Ear & Hearing*, **35**,491-505, (2014).

[10] ISO 1999: 2013 Acoustics – Estimation of noise-induced hearing loss, *International Organisation for Standardisation*, Geneva, 2013.

[11] Williams W, Beach E, Gilliver M. "Clubbing – the cumulative effect of noise from attendance at dance clubs on whole-of-life noise exposure", *Noise & Health*, **12**, 155–158, (2010).

[12] Carter L. *Prevalence of hearing loss and its relationship to leisure sound exposure*, report of a study carried out by the National Acoustic Laboratories through a grant provided by the Office of Hearing Services, Department of Health and Ageing, Canberra, 2012. Available at https://www.google.com.au/webhp?sourceid=chrome-instant&ion=1&espv=2&ie=UTF-8#q=Carter%2C+L+(2011)+Prevalence+of+hearing+loss+and+its+relationship+to+leisure+sound+exposure%2C"

[13] Williams W, Carter L, Seeto M. "Hearing thresholds for a population of 11 to 35 year old Australian females and males", **53,** 289–293, (2014).

[14] ISO 8253-1:2010 Acoustics - Audiometric test methods - Part 1: Pure-tone air and bone conduction threshold audiometry, *International Organisation for Standardisation*, Geneva, 2010.

[15] Fisher M, Williams W. "Reduced conditions on ambient noise levels for in-situ audiometric testing"' Technical Note, *Acoustics Australia,* **41**, 232–233, (2013).

[16] Williams W. *Life-time profiles of sound exposure – what is a safe exposure?* Final report prepared for the Office of Hearing Services (2011), Department of Health and Ageing by the National Acoustic Laboratories, funded through the Hearing Loss Prevention Programme, 2011. Available at http://hearingservices.gov.au/wps/wcm/connect/8a71756e-9aac-4532-82e7-73e30d6fa09c/Lifetime_profile_exposure_sound_what_safe_HLPP2.pdf?MOD=AJPERES&CONVERT_TO=url&CACHEID=8a71756e-9aac-4532-82e7-73e30d6fa09c

[17] I – INCE. *Technical Assessment of Upper Limits on Noise in the Workplace*, International Institute of Noise Control Engineering, I-INC Publication 97-1. Noise/News International, 203–216, 1997.

[18] Beach E, Gilliver M, Williams W. "The NOISE (Non-Occupational Incidents Situations and Events) database: A new research tool", *Annals Leisure Research*, **16**, 149–159, (2013).

[19] Schlauch RS, Carney E. "The challenge of detecting minimal hearing loss in audiometric surveys", *American Journal of Audiology*, **21,** 106–119, (2012).

[20] Carter L, Williams W, Seeto M. "Otoacoustic emission findings of an Australian cross-sectional hearing study", *International Journal of Audiology*, in press, (2015).

[21] ISO 7029: 2000 Acoustics – Statistical distribution of hearing thresholds as a function of age, *International Organisation for Standardisation*, second edition, Geneva, 2000.

[22] Beach, EF, Gilliver, M, Williams, W. "Leisure noise exposure: Participation trends, symptoms of hearing damage, and perception of risk", *International Journal of Audiology*, **52**, S20–S25, (2013).

[23] Kujala T, Shtyrov Y, Winkler I, Saher, M, Tervaniemi M, Sallinen M, et al. "Long-term exposure to noise impairs cortical sound processing and attention control", *Psychophysiology*, **41,** 875–881, (2004)

[24] Kumar AU, Ameenudin S, Sangamanatha AV. "Temporal and speech processing skills in normal hearing individuals exposed to occupational noise", *Noise & Health*, **14**, 100–105, (2012).