

PhD thesis statement:

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As first author of the paper “*An estimation of the whole-of-life noise exposure of adolescent and young adult Australians with hearing impairment?*” I, Lyndal Carter, confirm that I have made the following contributions: devised the study concept, performed data collection, performed data analysis under the guidance of the co-authors, and drafted the manuscript in full, in consultation with the co-authors.

Signed..........Date:.....21/7/16....

As supervisor for the candidature upon which this thesis is based, I can confirm that the authorship attribution statements above are correct.

Supervisor Name: Prof Deborah Black

Signed..........Date:.....21/7/16....

Title: An estimation of the whole-of-life noise exposure of adolescent and young adult Australians with hearing impairment.

Lyndal Carter¹, Deborah Black³, Anita Bundy³, Warwick Williams^{1,2}

1 National Acoustic Laboratories, Sydney, NSW, Australia.

2 The HEARing CRC, East Melbourne, Victoria, Australia.

3 The Faculty of Health Sciences, University of Sydney, New South Wales, Australia.

Keywords: adolescents; disability; hearing; injury; leisure; noise; participation; young adults.

Abbreviations: CI = cochlear implant; HI = hearing impaired; HTL = hearing threshold level; L_{Aeq} = long-term equivalent average sound level; NAL = National Acoustic Laboratories; NH = normal (non-impaired) hearing; NIPTS = noise-induced permanent threshold shift; NOISE = Non-Occupational Incidents, Situations and Events; $Pa^2 h$ = Pascal squared hours; PHP = personal hearing protector; PSP = personal stereo player; QoL = quality-of-life.

Definitions: Loud sound experienced during leisure activities has been referred to as “leisure noise” or “social noise” (Smith, et al., 2000). In this review the term *leisure noise* is used. It is important to note that while the term *noise* sometimes denotes *unwanted* sound, leisure noise is often not only acceptable to the listener, but is sought after as a pleasurable experience (Hidecker, 2008; Gilliver, et al., 2013).

The terminology surrounding “hearing loss” also varies in the literature and among authorities. Three concepts are generally defined: (1) Threshold “shift” (or threshold impairment), which refers to a deviation of individual hearing threshold levels (HTLs) from a baseline, that is, either the HTL of the individual or a recognised audiometric standard (WHO, 1980), (2) “noise-induced (permanent) threshold shift” or “noise-induced hearing loss”, referring to threshold shift attributable to noise exposure alone and, (3) “hearing impairment” (or hearing

disability/hearing handicap), which refers to the individual disadvantage in everyday life imposed by HTL shift, particularly in terms of understanding conversational speech (ISO, 1990). In this article “hearing loss” is synonymous with HTL shift.

There is currently no universal definition of “normal hearing” (Schlauch & Carney, 2012). In this article “normal hearing” implies HTLs similar to those of reference populations (e.g., ISO 7029, 2000).

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ABSTRACT

Background: Since amplified music gained widespread popularity, there has been community concern that leisure-noise exposure may cause hearing loss in adolescents and young adults who would otherwise be free from hearing impairment. Repeated exposure to personal stereo players (PSPs) and music events (e.g., night-clubbing, rock concerts and music festivals) are

of particular concern. The same attention has not been paid to leisure-noise exposure risks for young people with hearing impairment (either present from birth or acquired prior to adulthood). This article reports on the analysis of a subset of data (leisure participation measures) collected during a large, two-phase study of the hearing health, attitudes and behaviours of 11- to 35-year-old Australians conducted by the National Acoustic Laboratories (NAL) ($n = 1667$ hearing threshold level datasets analysed). The overall aim of the two-phase study was to determine whether a relationship between leisure-noise exposure and hearing loss exists.

Purpose: In the current study, the leisure activity profiles and accumulated (“whole-of-life”) noise exposures of young people with, (1) hearing impairment and (2) with normal hearing were compared.

Research Design: Cross-sectional cohort study.

Study Sample: Hearing impaired (HI) group, $n = 125$; normal (non-impaired) hearing (NH) group, $n = 296$, analysed in two age-based subsets: adolescents (13- to 17-year-olds) & young adults (18- to 24-years-olds).

Data Collection and Analysis: Participant survey. The χ^2 test was used to identify systematic differences between the leisure profiles and exposure estimates of the HI and NH groups. Whole-of-life noise exposure was estimated by adapting techniques described in ISO 1999.

Results: For adolescents, leisure profiles were similar for the two groups and few individuals exceeded the stated risk criterion. For young adults, participation was significantly lower for the HI group for 7 out of 18 leisure activities surveyed. Activity diversity and whole-of-life exposure were also significantly lower for the HI group young adults. A substantial number of individuals in both groups reported participation in leisure activities known to involve high noise levels (HI < NH). The individual whole-of-life exposures for the HI and NH participants were estimated and group median exposures were calculated. The median exposure for HI

group young adults was significantly lower than for the NH group (710 versus 1,615 Pa²h [Pascal squared hours]).

Conclusions: The number of young adults with estimated exposure above the chosen noise-risk criterion in the NH group is concerning. With respect to the goals of hearing loss prevention initiatives, the more conservative social behaviour (e.g., less night-clubbing) observed among HI group young adults may be regarded as a positive finding, but it could also signify relative social disadvantage for some young adults with hearing impairment.

INTRODUCTION

Leisure activity is a significant part of life. Henry (1998) cited evidence from occupational therapy literature emphasising the importance of leisure and play for children's development of identity, self-esteem, physical and cognitive skills, and in providing enjoyment, relaxation and achievement. For adolescents and young adults, some popular and socially important leisure activities involve noise-injury risk (e.g., nightclub attendance, pop/rock music concerts). Noise injury has typically been regarded as being manifested by hearing threshold level (HTL) shift; however, evidence now suggests that there may be subclinical damage occurring between the cochlea and the auditory nerve preceding HTL shift (Kujawa & Liberman, 2009; Stamper & Johnson, 2015).

Noise exposure is cumulative and three main factors interact to determine individual noise-injury risk: (a) the average loudness (long-term equivalent average sound level, L_{Aeq}) of sound during each activity or event, (b) the duration of each event, and (c) the total number of high-noise events experienced over the life time (Williams et al., 2015). The average risk of HTL shift for people with a normal hearing baseline can be meaningfully estimated based on lifestyle profiles (Williams, 2008), although some individual variation in susceptibility to noise injury has been demonstrated in well-controlled human and animal studies (Henderson et al., 1993; Davis et al., 2003). That is, individuals with similar baseline hearing thresholds exposed to exactly the same noise may develop differing amounts of noise-induced permanent threshold shift (NIPTS) (Henderson, et al., 1993). Individual estimation of noise-injury risk involves some level of approximation; however, it is still critical to examine the association between noise exposure and health effects. Hidecker (2008) emphasised that noise exposure and audiometric data are needed to investigate the causal connection or the dose-response relationship between noise exposure and NIPTS.

There have been a number of estimations of the prevalence of NIPTS for young populations using various samples and methodologies (Schlauch & Carney, 2012; Carter et al., 2014). In the Australian context, it was recently concluded that around 14% of 11- to 35-year-olds were at risk for noise injury from leisure-noise exposure (Beach et al., 2013b). As noted by Gilliver et al. (2013), there are now a range of educational resources offering hearing loss prevention advice to young people. A number of published reports have described various approaches and their outcomes (Martin et al., 2006; Widen, 2006; Griest & Folmer, 2007; Weichbold & Zorowka, 2007). Under a recent Australian hearing health initiative (HEARsmart™) an educational website, “Know Your Noise” (knowyournoise.nal.gov.au), has been developed, which allows noise risk to be self-estimated based on lifestyle factors, i.e., work and leisure activity participation and the use of personal hearing protectors (PHP) (Beach & Sewell, 2015). Users of the “Know Your Noise” website can see how their risk estimation changes when lifestyle details are varied. Personalised feedback about noise risk is provided in the form of simplified comparison statistics (individual risk versus average risk for others of a similar age). As for the current analysis, risk estimates provided by the website are based on data and methods described in ISO 1999 (ISO, 2013).

Like other hearing health initiatives, “Know Your Noise” assumes a target audience without hearing impairment prior to noise exposure. Currently there is little evidence from which individuals with existing sensorineural hearing loss can be readily and specifically informed about noise risk. This lack of information is significant. Ching et al. (2013) described the concern about excessive amplitude levels during hearing aid use as similar to that for regularly noise-exposed workers (as per, OSHA, 1981; NIOSH, 1998; ISO, 2013). This concern for hearing aid wearers arises from the fact that, by design, hearing aids increase the sound pressure level delivered to the wearer’s ear (Dolan & Maurer, 1996), therefore, potentially accelerating

the accumulation of noise exposure. On the other hand, it has also been observed that an ear with pre-existing sensorineural hearing loss sustains less HTL shift from a given exposure than a non-impaired ear (Macrae, 1991a; 1992).

The prevalence and extent of hearing aid-related NIPTS has been debated (Markides, 1971; Rintelmann & Bess, 1977; Reilly et al., 1981; Bentler, 2000) and still remains unclear. Hearing-aid related HTL shifts were reported in some early clinical studies, most compellingly when observed in monaurally aided ears while the unaided ear remained unaffected (Macrae & Farrant, 1965; Ross & Lerman, 1967; Macrae, 1968; Roberts, 1970). However, since the time of these studies, technological developments in digital signal processing (particularly, nonlinear amplification) have allowed automatic control of hearing aid amplification as a function of input level (Ross, 2011; Dillon, 2012) which would be expected to improve overall safety. Prediction of hearing aid-related NIPTS using mathematical modelling was also the subject of earlier publications (see Humes & Jesteadt, 1991; Macrae, 1991a,b; 1994). Macrae (1991a) predicted that a small amount of NIPTS was inevitable for wearers with severe-to-profound sensorineural hearing loss (due to the high amount of gain required to make speech audible). Dolan and Maurer (1996) emphasised that these studies addressed the use of hearing aids for listening at “normal conversational levels”, in situations such as the classroom or home, rather than in high-noise environments. More recently, a modelling study by Ching et al. (2013) described the prediction of asymptotic threshold shifts associated with non-linear hearing aid use, with devices fitted according to contemporary prescriptive procedures. It was concluded that with high input levels, unsafe amounts of asymptotic threshold shift would still be expected to occur for individuals with more severe hearing loss.

To date, there has been little systematic information about the leisure activities of young people who wear hearing aids and/or cochlear implants (CIs). Punch et al. (2004) also noted that information pertaining to the work life of young people with hearing impairment was lacking. Therefore, knowledge about the range of input levels young hearing aid wearers are likely to experience in everyday life is limited. Furthermore, studies of young people with hearing impairment tend to be biased towards users of CIs (Hogan, et al., 2011), for whom noise risk is not a critical issue as the signal provided by CIs is non-acoustic. In general, although hearing impairment is one of the most common disabling conditions in young people (Keilmann et al., 2007) and considered a “social” handicap (Watson et al., 1990), its effects on participation and emotional well-being have been under-researched (Tsai & Fung, 2005; Hogan, et al., 2011).

With respect to the prevention of NIPTS in hearing aid wearers, currently and widely used paediatric hearing aid-fitting protocols (see King, 2010; AAA, 2013) emphasise the importance of matching amplification (gain and maximum power output) closely to prescribed targets, monitoring hearing thresholds regularly for indications of threshold shift, and informing young hearing aid wearers and their parents about the importance of using hearing aids at the recommended volume setting. Ching et al. (2013) also emphasised the need for clinicians to advise children (or parents) against the use of amplification in high-noise environments and to promote the use of PHPs during extended noise exposure. In general, clinicians are advised to recommend that hearing aid wearers (of any age) should “avoid prolonged exposure to high noise levels” (Dillon, 2012, p. 333).

While providing general advice fulfils an evidence-based duty of care to clients, participation in everyday activities may be compromised if an overly conservative approach to noise risk management is adopted. For example, a parent may ask their child’s audiologist whether

school dances or learning a loud musical instrument (e.g., trumpet) should be avoided. The clinician may support avoidance or prescribe the rigorous use of PHPs. However, turning off hearing aids or using PHPs during a social or musical activity may make it difficult for a child to fully participate. With the existing evidence base, it is difficult to provide information that is reliable and specific enough for parents (or older children) to meaningfully weigh up the risks versus benefits in such instances. Over-generalised counselling may lead to parent decisions based on misperceptions of high-level risk when the actual risk is relatively low. It has been noted in family therapy research that unnecessary parental concern in environments that actually involve minimal risk can become counter-productive (Ungar, 2009).

Development of meaningful participation measures is complex (Coster, et al., 2012) but it has been demonstrated that leisure participation can be reliably measured in adolescents with, and without, disabilities (Henry, 1998). Participation is multidimensional, “involving type and frequency of activity as well as environmental and personal factors” (Raghavendra et al., 2011, p. 148) and a number of different participation measures have been described (Henry, 1998; King et al., 2004; Bedell, 2009; Rosenblum et al., 2010; Solish et al., 2010; Ullenhag et al., 2014). Phillips et al. (2013) noted that frequency, duration, and intensity of activity performance are important in measuring extent of involvement (citing Bedell & Coster, 2008; Dijkers, 2010). Coster (2012) also emphasised the importance of frequency as an objective measure. Participation measures are distinct from health-related quality-of-life (QoL) measures, which primarily investigate individual satisfaction with respect to health status (Forsyth & Jarvis, 2002) as opposed to extent of activity involvement.

This article presents an analysis of activity participation data, extracted from comprehensive surveys used in an Australian two-phase hearing health study. This study was supported by

the Australian Commonwealth Government, Office of Hearing Services and the National Health and Medical Research Council, in the context of community concern about the leisure-related, noise-injury risk of adolescents and young adults. The first study phase has been reported previously (see Carter, 2011; Williams, et al., 2014; Carter et al., 2015; Williams, et al., 2015). The participation measures used in this study, and described in the current article, were specifically developed by the National Acoustic Laboratories (NAL), as no existing measures were applicable to the specific research objectives and participant age range of this study. Participant profiles of frequency and duration of involvement in a range of leisure activities were gathered primarily to estimate individual whole-of-life noise exposure. Individual satisfaction with leisure activities (i.e., QoL) was not examined. The main purpose of the analyses described in this article was to compare the leisure activity profiles and accumulated (whole-of-life) noise exposure of a group of young Australians with hearing impairment (HI group) with an age-matched group of normal (non-impaired) hearing participants (NH group).

Research hypotheses

It was hypothesised that (a) the reported leisure participation of young people in the HI group would be lower than the NH group and (b) the estimated whole-of-life noise exposure of the HI group would also be lower.

This hypothesis was based on the knowledge that in noisy environments, people with sensorineural hearing impairment may be affected by communication difficulty (Hallberg & Carlsson, 1991) and/or listening discomfort (i.e., decreased dynamic range related to cochlea hair cell damage or “recruitment”; Dillon, 2012) and therefore may be averse to noisy leisure activities. In addition, many young Australians with hearing impairment have regular contact

with hearing professionals and it was therefore speculated that as a group they may be more exposed to hearing loss prevention messages than their peers with normal hearing.

The estimated whole-of-life exposures of individuals with hearing impairment presented here are a first-order approximation and may be slightly conservative. Hearing aid parameters and patterns of use (i.e., volume setting, listening environments) may interact with participation profiles to influence *each individual's* whole-of-life noise exposure to varying degrees.

METHOD

The leisure activity profile data presented here were extracted from a larger hearing health dataset collected between 2009 and 2014, over two study phases.

Participants: phase 1

A total of 1,407 participants provided audiological data, 723 were interviewed, and 1,059 completed hearing health, behaviour and attitudes surveys in phase 1. All participants were residents of New South Wales, most (~85%) within the greater metropolitan area of Sydney. The remainder resided in regional areas. Recruitment initially targeted 11- to 17-year-olds (school students) with the only inclusion criterion being age. The protocol was later extended to include 18- to 35-year-olds (tertiary students and employees in a range of work settings). Survey and structured interview instruments used are publicly available (Carter, 2011). A subset of participants who provided survey data was selected as the NH group for the current analysis according to the following inclusion criteria: better ear four frequency average hearing level at 500, 1000, 2000 and 4000 Hz \leq 20 dB HL, and absence of disabling conditions (i.e., physical, intellectual or sensory). A number of phase 1 participants were undertaking tertiary level music study at the time of completing the survey. Data for these participants were excluded from the current analysis on the basis that the level of musical activity participation

required in this vocational area is not typical of the population of interest and would skew results for music-related items for the NH group.

Participants: phase 2

Retrospective HTL data were obtained for a total of 260 participants with confirmed hearing threshold impairment. In all, 237 participants provided both retrospective HTL and complete survey data. Approximately 80% were resident in the greater metropolitan area of Sydney. Most were recruited via Australian Hearing (the national hearing service provider to young people up to the age of 26 years). Age was again the only specific inclusion criterion. Invitation packages were distributed to potential participants during routine follow up assessments at 15 participating hearing centres in New South Wales. The overall take-up rate for those invited to participate was low (~14%); however the survey return rate for those providing consent to participate was high (~92%). Hearing loss was sensorineural in nearly all cases. The degree (see Table 4.1) and configuration of hearing losses varied. The majority of participants were diagnosed with hearing impairment before school age, and almost all by adolescence. Most participants were fitted with hearing aids. Only 8% of participants ($n = 10$) used CIs only. Detailed clinical information (including serial audiograms, hearing aid data and case histories) were collected from the participants' Australian Hearing clinical files. In the majority of cases, continuous records from the time of first diagnosis were available. For the current analysis, disability in addition to hearing impairment was the only exclusion criterion apart from age.

Participants: current analysis

As noted previously, the target age range for the overall two-phase study was 11 – 35 years. However, age differences in leisure profiles have been reported (e.g., Shikako-Thomas, et al.,

2008; ABS, 2009; Coster, et al., 2012; Beach, et al., 2013b) and therefore participants for the current analysis were selected in two age-based subsets: (A) 13 – 17 years (adolescents) and (B) 18 – 24 years (young adults) (see Table 4.1). These age divisions were chosen on the basis that “adolescence” commences at around 13 years of age, and extends through the time period that young people are still primarily dependent on parents/adults (Altman, 1996). By 18 years of age, most young people have completed high school and may also have gained the independence of driving (Coster, et al., 2012). Furthermore in Australia, 18 years is the minimum age for legal entry to licensed premises (i.e., nightclubs and bars). Australian Government census data (ABS, 2009) indicated that most attendees at loud popular music concerts were aged between 18 and 24 years, with the likelihood of attendance decreasing with age. Therefore, 24 years was chosen as the upper age limit for the current investigation.

Table 4.1 provides an overview of participant details. For the NH group, the median, better-ear, four-frequency average hearing level at 500, 1000, 2000 and 4000 Hz for adolescents was 5 dB HL (range = 0 – 19 dB HL) and for young adults was 4 dB HL (range = 0 – 15 dB HL). To provide a general demographic profile for each group, decile rankings of socio-economic status (SES) were assigned to each participant based on town/suburb of residence (according to Census of Population and Housing data, ABS, 2006). The percentages of participants in the three most socio-economically advantaged categories (i.e., 8, 9 and 10) by group were the following: adolescents, HI = 56%, NH = 38%; young adults, HI = 47%, NH = 71%.

Table 4.1: Participant details.

	HI group	NH group	
Total # survey responses: >10.99 < 35.99 yr	<i>n</i> = 267	<i>n</i> = 1059	
<i>*Analysis subsets: (% total participant group)</i>			
(A) >12.99 < 17.99 yr	46 (17%)	165 (16%)	
(B) >17.99 < 24.99 yr	79 (29%)	131 (12%)	
Mean participant age (A)	14.9	15.8	
Mean participant age (B)	21.1	22.4	
Participant gender (A) (% age subset)	Female: <i>n</i> = 26 (56.5%) Male: <i>n</i> = 20 (43.5%)	Female: <i>n</i> = 89 (53.9%) Male: <i>n</i> = 76 (46.1%)	
Participant gender (B) (% age subset)	Female: <i>n</i> = 56 (70.9%) Male: <i>n</i> = 23 (29.1%)	Female: <i>n</i> = 78 (59.5%) Male: <i>n</i> = 53 (40.5%)	
HI group			
<i>Degree of pure tone hearing loss (better ear 4FAHL_{500, 1000, 2000, 4000 Hz})[†]</i>			
Mild (21-39 dB)	Moderate (40-59 dB)	Severe (60-89 dB)	Profound (90+ dB)
(A) 17 (37%)	16 (34.8%)	2 (4.3%)	4 (8.7%)
(B) 13 (16.5%)	25 (31.6%)	18 (22.8%)	13 (16.5%)
Reported hearing aid/cochlear implant use			
Hearing aids only	Cochlear implant	Devices no longer used	
(A) 36 (78%)	6 (13%)	3	
(B) 58 (73%)	16 (20%)	2	

Notes: Some CI wearers also use a conventional hearing aid in the opposite ear.

*** After exclusion criteria applied (i.e., disability in addition to hearing impairment, missing HTL or survey data, poor survey completion, tertiary music students).

[†] HI group includes cases with better ear 4FAHL < 21 dB (re; asymmetrical HTLs).

Ethics

Protocols were approved by the Australian Hearing Human Research Ethics Committee, the Human Research Ethics Committee, University of Sydney, and the New South Wales Department of Education and Training, Student Engagement and Program Evaluation Bureau. Participation was voluntary and there were no individual incentives for taking part.

Survey and interview forms

Protocol development was informed by a review of previous literature pertaining to the effects of noise on younger populations (see Carter, et al., 2014). Previous hearing health surveys, particularly those reported by Serra et al. (2005) and Biassoni et al. (2005), influenced the selection of item content. Children's focus groups were also used in the development process. Instrument piloting was carried out in the early stages of phase 1 of the study and any difficulties with items were addressed. Further piloting of survey versions for phase 2 of the study was undertaken, to ensure content was equally appropriate for young people with hearing impairment. In this context, expert feedback was obtained from paediatric audiologists, psychologists, an occupational therapist, statistician, and a medical practitioner. For phase 2 participants < 18 years of age, separate parent and participant forms were used. Demographic and participant hearing health items were included in the parent form. This was intended to reduce the complexity of survey completion for younger participants with hearing impairment, given that it is well documented that childhood hearing loss is associated with literacy and language development issues (Hogan, et al., 2011).

In both study phases the survey was completed by the participant at home, either in paper form or online (as preferred). The format was self-report; however the instructions for under-18-year-olds allowed for parents to assist where required (particularly in the recall of past activities

or incidents). All participant survey versions contained a concise measure of activity participation referred to as the “leisure table” (see Appendix 5, Q. 34 & Appendix 6, Q. 35). Figure 4.1 shows the leisure table response format (HI survey versions).

Go to live music (e.g., bands, concerts, musicals) at smaller venues (e.g., hall, theatre, club etc.)			
<p>About how much have you done this activity?</p> <input type="checkbox"/> Never → go to next activity <input type="checkbox"/> Less than once a year <input type="checkbox"/> 1-2 times a year <input type="checkbox"/> Once every few months <input type="checkbox"/> Once a month <input type="checkbox"/> Once every 2-3 weeks <input type="checkbox"/> Once a week <input type="checkbox"/> More than once a week	<p>About how long do (did) you do the activity each time?</p> <p>_____ hours each time</p> <p>How old were you when you first did this activity?</p> <p>_____ years of age</p> <p>How many times a week?</p> <p>_____ times</p>	<p>How many years altogether have you done this activity?</p> <p>_____ years in total</p> <p>Hearing aids/CI worn? (switched ON)</p> <input type="checkbox"/> Never <input type="checkbox"/> Sometimes <input type="checkbox"/> About half the time <input type="checkbox"/> Most of the time <input type="checkbox"/> Always	<p>Hearing protection used?</p> <input type="checkbox"/> Never <input type="checkbox"/> Some of the time <input type="checkbox"/> Mostly/always Type _____

Figure 4.1: Format of questions in “leisure table” section of hearing health survey (HI versions).

The format for NH adults was identical to this, apart from exclusion of the device usage item. In the survey version completed by the adolescent NH group, the leisure table format differed slightly. It contained identical frequency, total years participation, and PHP use questions, but omitted specific detail about duration (i.e., How many hours per week?, How many hours each time?). To maximise the consistency of responses, the activity descriptions were very specific. The total number of activity items was limited with respect to the burden of completion time. For adolescent participants, 20 items were initially included in the leisure table but 6 were subsequently added during the course of phase 1 of the study. All 26 of these items were included in the HI group survey for adolescent participants; however, only data for the 20 common items were used in the current analysis. The adult surveys for both the HI and NH groups contained 15 identical activity items (see Appendix 3, Q. 35).

Participants were asked to provide details of any other noise exposure (including work activities) using the same format as the leisure table items. In addition to the leisure table items, other noise-related questions included; exposure to sudden impulse noise (e.g., gunshots, blasts), personal listening to recorded music (personal stereo players [PSPs], speakers), and attendance at dances/night clubs (young adult versions only). To account for any parent influence over adolescent participant responses, several music-listening questions were partially duplicated in a face-to-face interview as a reliability measure during phase 1 of the study. Frequency and preferred volume for PSP use from this interview data (see Appendix 5) were used for the current analysis. For logistical reasons participants with HI were not interviewed, however the relevant music-listening items contained in the NH group interviews were duplicated in the take-home survey for < 18-year-olds in phase 2. Personal music-listening items (interview and survey) contained subjective rating scales allowing the participant to provide an indication of typical listening levels. The use and reliability of these scales has been described previously (see Gilliver et al., 2012; Williams et al., 2013).

Analysis

Comparing leisure profiles

The frequency data from the leisure table and personal music-listening questions were used for comparing the leisure activity profiles of the HI and NH groups. As illustrated in Figure 4.1, the leisure table provided eight participation frequency response options per activity. However, these categories needed to be aggregated to provide sufficient power for analyses. Therefore, these eight options were collapsed into four categories as follows: 1 = never; 2 = once or twice ever- once or twice/year; 3 = once every 2 - 6 months; 4 = monthly - once/week or more. Collapsing categories in this way also allowed direct comparison of the current data with earlier

NAL data (e.g., Beach, et al., 2013b). Pearson's χ^2 testing was applied to the recoded leisure table data to examine differences between groups.

Similar to one of the scoring methods used in the Children's Assessment of Participation and Enjoyment (CAPE) described by Law et al. (2006), the absolute number of activities reported (regardless of frequency of participation) was tallied as a measure of participation "diversity". While information about activity diversity was not essential for estimating noise exposure, it provided another perspective and point of comparison of the leisure-behaviour profiles for the HI and NH groups. The χ^2 testing was again used to look for a difference in diversity scores between the HI and NH groups. IBM SPSS Statistics, version 22, was used for statistical analyses. The standard criterion for statistical significance for all tests was set at $\alpha = 0.05$.

Estimating whole-of-life exposure

Whole-of-life noise exposure was calculated for each participant, based on activity frequency and duration for leisure table items, music listening, occupational, and any other reported loud-noise exposure (Williams, 2008). For each activity, the sound exposure in Pascal squared hours ($\text{Pa}^2 \text{ h}$) was calculated, based on (a) an estimated average sound level (L_{Aeq}) for the reported activity, (b) the participant's average number of hours of exposure per week or month, and (c) the total number of years of exposure. Where the simpler leisure activity table format was used (i.e., for NH adolescents) average activity durations derived from NAL's Non-Occupational Incidents, Situations and Events (NOISE) database were substituted. The NOISE database is a comprehensive catalogue of objective dosimetry measures obtained in a wide range of real-life environments (Beach et al., 2013a). In 16 (10%) cases, where the simpler leisure table format was used, participation frequency was reported but the total number of years of

participation was omitted. Whole-of-life exposure estimates for these participants were not calculated.

The estimated L_{Aeqs} of PSPs used in the exposure calculations were based on previously published data (Williams, 2005). Estimated L_{Aeqs} for other activities came from the NOISE database (see above). If PHP use during the activity was reported by the participant, a systematic reduction in the estimated noise exposure level was made. It was assumed that on average PHP use would reduce exposure by 10 dB. If the participant reported consistent use of PHPs the exposure (in $Pa^2 h$) was reduced by a factor of 10. If reported frequency of use was “sometimes” it was assumed that PHPs were only used half the time and the reduction was adjusted accordingly. Finally, estimated exposures from all activities were summed. This total represents the individual estimated whole-of-life exposure for the purposes of this analysis.

An “acceptable” whole-of-life exposure criterion for age was calculated (in Pa^2h) by multiplying life years (age) by 222.2 Pa^2h . This was chosen on the basis that 222.2 Pa^2h in a single life-year represents the defined action level, or agreed acceptable exposure standard (85 dB for 8 working hours, or 1.01 Pa^2h), for continuous workplace noise in many workplace health & safety jurisdictions around the world (Williams, 2008; Williams, et al., 2015). Because estimation on the basis of reported noise exposure history will always be approximate, results are reported rounded to the nearest 5 Pa^2h . Participant age and estimated whole-of-life noise exposure for the HI and NH groups were not normally distributed and appropriate statistical tests were applied.

RESULTS

Overall, the research hypothesis that “leisure participation would be lower for young people with HI and hence whole-of-life exposure would be lower” was confirmed for the young adults on measures of participation frequency and diversity. It was not, however, supported for the adolescents.

Frequency of participation

Frequency of participation was compared using the χ^2 test. Participation once, or more than once, per month was regarded as “frequent” involvement. For adolescents, the common leisure table items and PSP use were included. Two pairs of related items with low participation rates were merged (“do motor sports”/ “watch motor sports” & “attend one day outdoor festival”/ “attend multiday outdoor festival”). In total, nineteen activities were compared. Figure 4.2 shows the proportion of adolescents reporting frequent participation by activity. Activities where frequency differed significantly overall for HI versus NH groups (according to cross-tabulation across four response categories) are indicated with an asterix (*). For two activities, “dance party/school dance” and “attend outdoor music festival”, a higher proportion of the adolescent NH group reported frequent participation. Conversely, for three activities, “play in orchestra”, “sing in choir”, and “use power tools”, a higher proportion of the adolescent HI group participated frequently. However, even where statistically significant, the differences in real terms were not clinically significant.

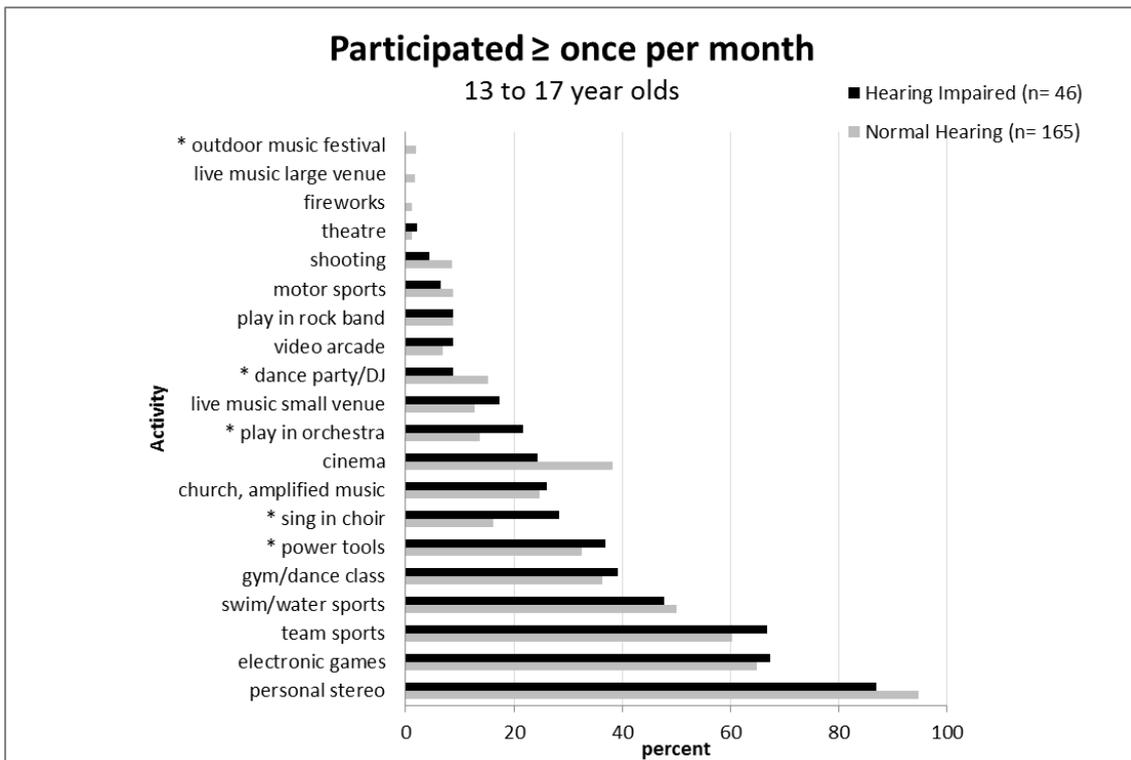


Figure 4.2: Frequent participation (once, or more than once, per month). * $p \leq 0.05$.

For young adults, participation frequency was compared for a total of 18 items (leisure table plus music listening and nightclub attendance). As illustrated in Figure 4.3, statistically significant differences were observed for eight items in this age group. In seven out of eight cases, the NH group reported higher participation. The differences for two items, “nightclub” and “pub/club” were particularly marked, with the NH group being twice as likely as the HI group to report attending nightclubs frequently.

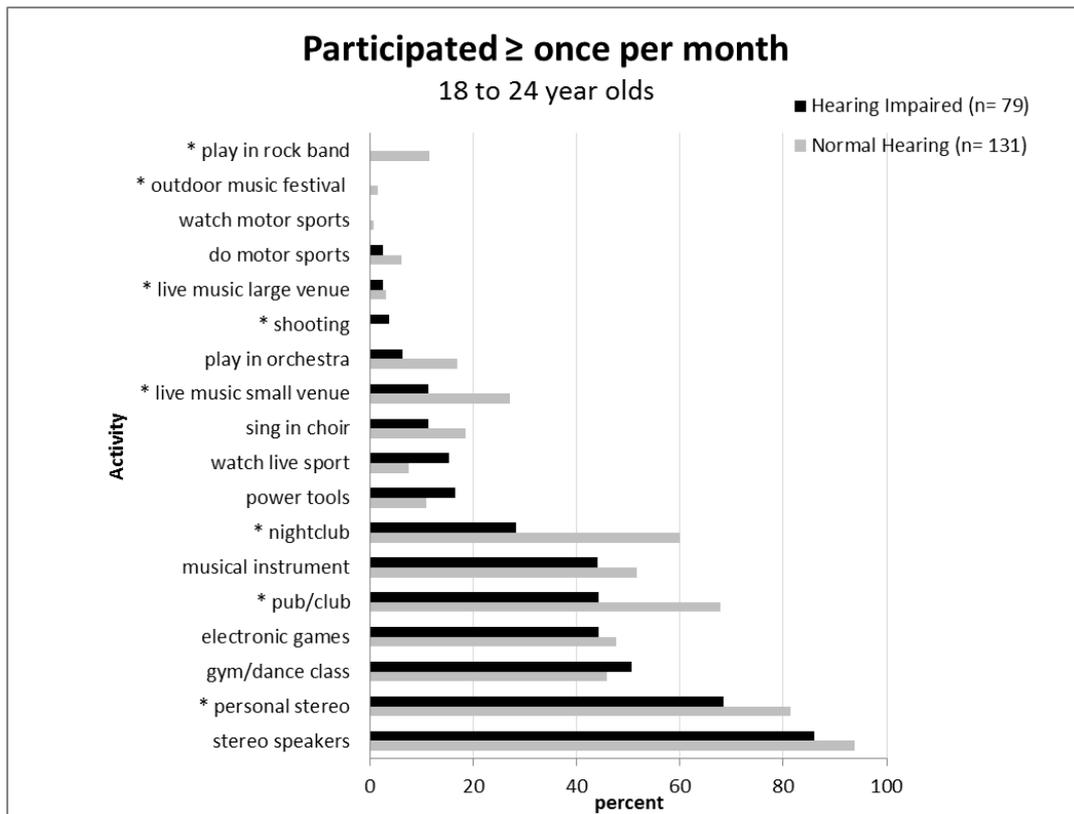


Figure 4.3: Frequent participation (\geq once/per month). * $p \leq 0.05$.

Activity diversity

As noted previously, the total number of activities with a participation frequency > “never” was tallied for each participant to compute a diversity score. The activities were those shown in Figures 4.2 and 4.3, apart from personal music-listening items (PSP and stereo use) which were not counted. The diversity scores were then collapsed into five and four categories for adolescents and young adults, respectively, as illustrated in Figures 4.4 and 4.5. The χ^2 test was used to compare the collapsed activity count for the HI and NH groups. For adolescents, there was no statistically significant difference in activity diversity between groups. For young adults, a statistically significant difference was observed. Of particular note, 21.6% of the HI group reported participation in four or fewer activities, compared with only 7.5% of the NH group.

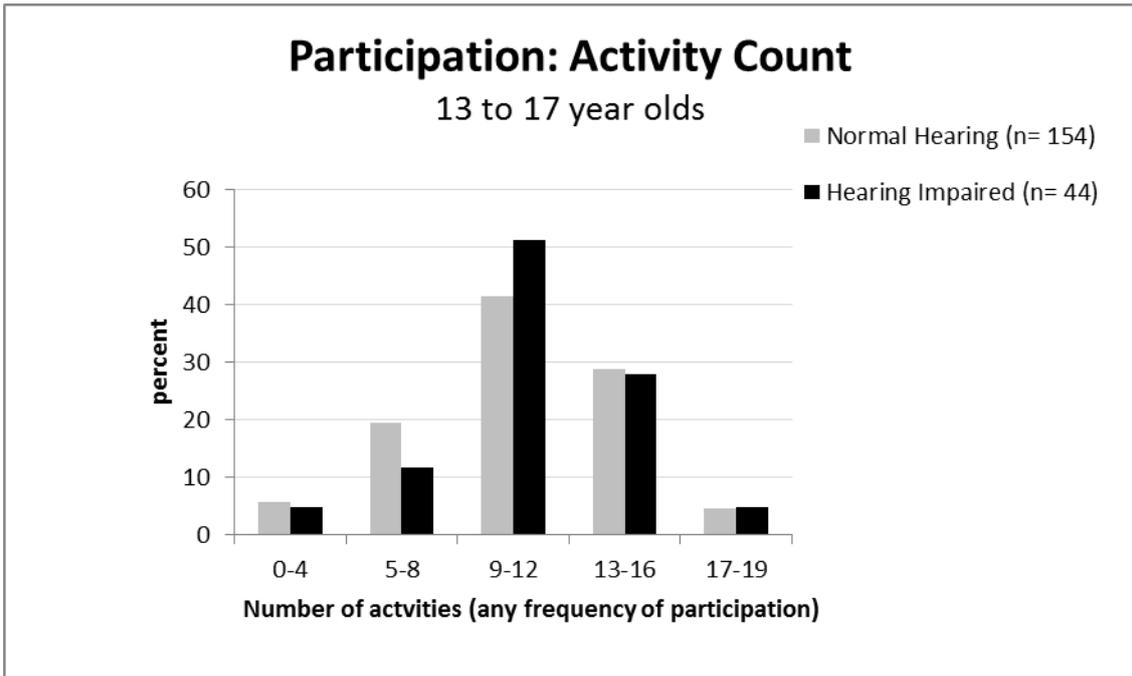


Figure 4.4: Activity diversity, adolescents.

Count of items with reported participation more than “never”.

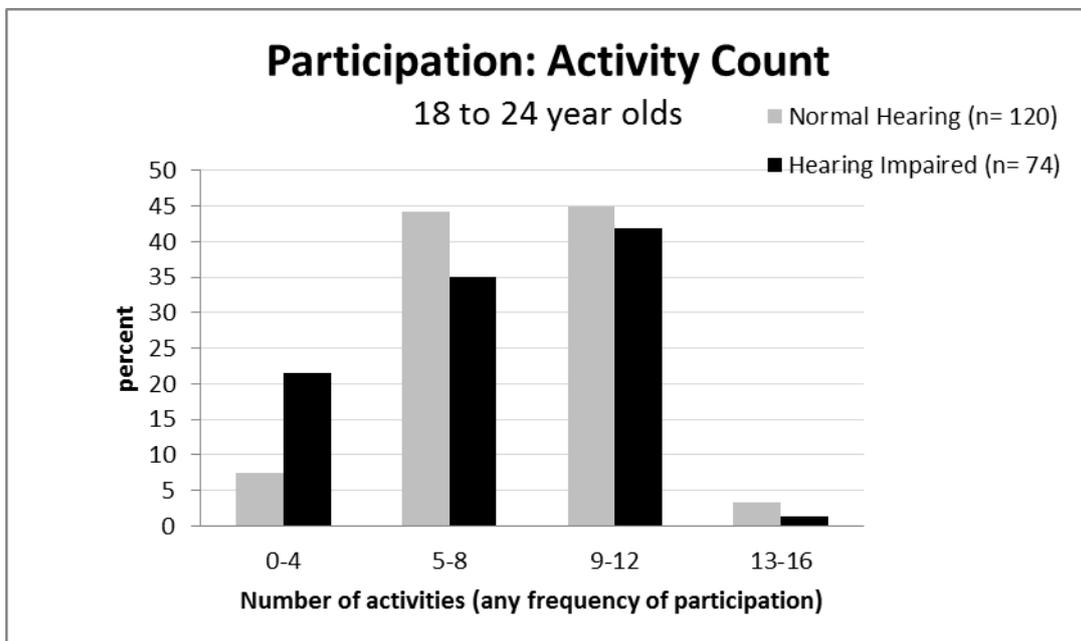


Figure 4.5: Activity diversity, young adults.

Count of items with reported participation more than “never”.

Whole-of-life noise exposure

The average whole-of-life exposure for each group was calculated and the Kolmogorov-Smirnov test showed that whole-of-life exposure was not normally distributed. Therefore, an independent samples Mann-Whitney U test was used to compare the median exposures of the HI and NH groups. For the adolescents, the approximate median exposure for the HI group (540 Pa²h) was higher than for the NH group (210 Pa²h). For the young adults the reverse was observed, with the HI group median (710 Pa²h) lower than the NH group median (1,615 Pa²h). A statistically significant difference between the group medians was observed for both age cohorts: adolescents, $p = 0.004$, and young adults, $p = 0.001$. For adolescents, four (8.6%) of the HI participants and three (1.8%) of the NH participants had an estimated exposure above the “acceptable” exposure criterion for their age. As noted previously, for 10% of the adolescent NH group (16 / 165 cases) an exposure estimate was not calculated due to missing data. In five of these missing data cases, no regular participation in high-noise activities was reported. However, the remaining 11 participants reported some regular participation in high-noise activities. If this participation were to translate into a whole-of-life exposure above the acceptable criterion, then the proportion for the NH group above criterion would increase to ~ 8%.

For the young adults, 8.9% (7) of the HI participants and 24.4% (32) of the NH participants were above the acceptable criterion. The highest estimated whole-of-life exposure for a participant in the HI group was 13,910 Pa²h. This was well below the two most extreme cases in the NH group which were 64,885 Pa²h and 33,055 Pa²h. A plot of the estimated whole-of-life noise exposure for each participant by age and the acceptable whole-of-life exposure criterion by age (connected triangle symbols) is provided in Figure 4.6.

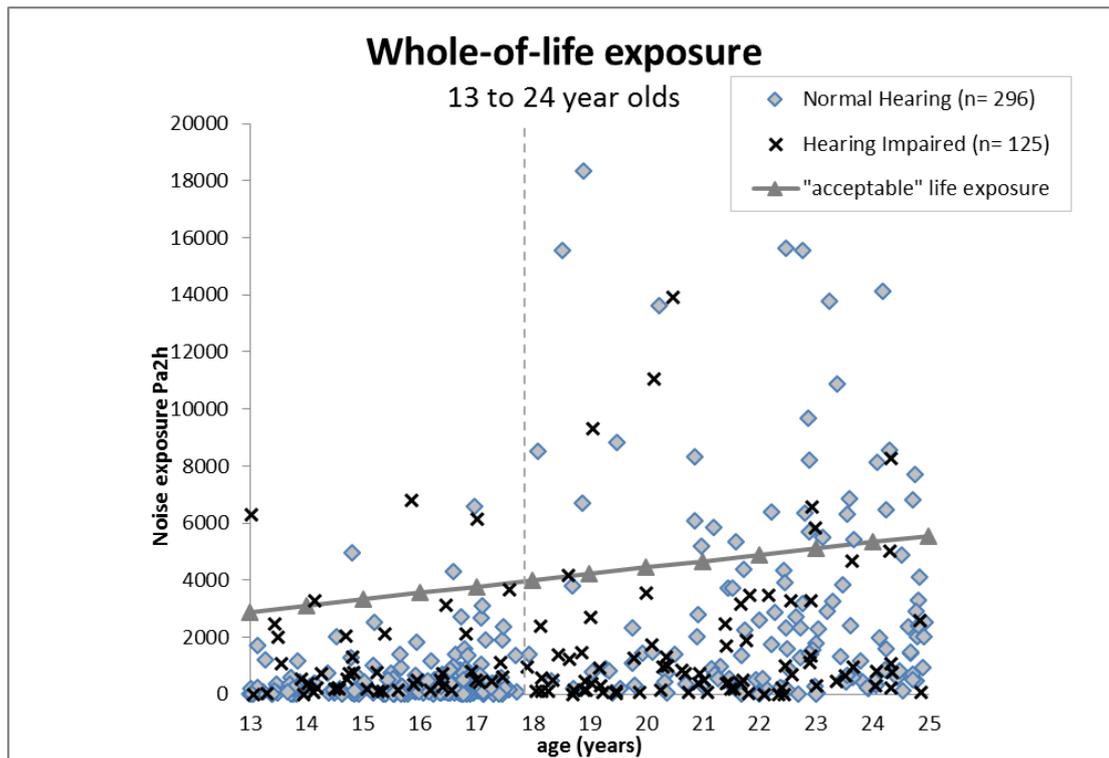


Figure 4.6: Estimated whole-of-life noise exposure, HI vs. NH young adults.

Notes: (1) “Acceptable” life exposure = $222.2 \text{ Pa}^2\text{h} \times \text{number of life years}$. Any contribution of hearing aid amplification was not included in this estimation.
 (2) Two extreme outliers have been omitted from this figure, both from the NH group: (a) 24.8 years, exposure $64,885 \text{ Pa}^2\text{h}$ and (b) 24.5 years, exposure $33,055 \text{ Pa}^2\text{h}$.

DISCUSSION

It was hypothesised that the leisure participation of young people in the HI group would be lower than the NH group, and hence their “whole-of-life” noise exposure would also be lower. This hypothesis was confirmed for the young adults, but not for the adolescents. From the point of view of hearing health, the lower relative whole-of-life exposure of the young adults with hearing impairment may be seen as a positive finding. However, it is possible that the lower frequency and diversity of participation observed for the HI young adults suggest relative leisure activity restriction (compared with the NH peer-group). This may, in turn, have negative QoL implications.

The observed similarity in leisure profiles of the adolescent HI and NH groups may relate to the fact that time is often more structured at this life stage. In general, adolescents' leisure activities are constrained by the time commitment of schooling, financial resources and parent attitudes to risk (Garton & Pratt, 1991; Forsyth & Jarvis, 2002; Jessup et al., 2010; Niehues et al., 2013). Many adolescents also regularly take part in organised sports (ABS, 2012). Furthermore, most adolescents depend on adults to facilitate participation, particularly when disability is a factor (Coster, et al., 2012). Previous research has shown that the leisure participation of young people with physical disabilities declines as they move through adolescence to early adulthood (King et al., 2007). The lower frequency and diversity of participation observed for the young adult HI group relative to the NH group, may suggest a similar trend in the case of hearing impairment. In this context, it is interesting to note that young people with hearing impairment are reported to experience difficulties surrounding the school-to-work transition, which include environmental and attitudinal barriers to participation (Punch, et al., 2004).

On average, the lower reported participation for the young adult HI group translated into lower whole-of-life noise exposure compared with the NH group, supporting the second part of the research hypothesis. A significant proportion of the young adult NH group (24%) had an estimated exposure above the acceptable exposure criterion for their age. This finding is comparable with earlier results for a sample of 18- to 24-year-olds ($n = 1000$) reported by Beach et al. (2013b), where 17.8% of participants were estimated as having whole-of-life exposures above the same criterion applied in the current study. The Beach et al. study probed only 5 leisure activities, as opposed to the 18 activities in the current study. However, the general convergence of risk estimates between the current study and those of Beach et al. (2013b) provides some assurance of the validity of the participation measure used. In the

current study, mean and median exposures for the young adults (HI and NH groups) were higher than for the adolescent groups, as would logically be expected, which also reflects positively on the validity of the participation measure used.

For the HI group, it is interesting to note that the proportion of cases above the “acceptable” noise exposure criterion was nearly identical for the adolescents and young adults (8.6% and 8.9%, respectively), whereas for the NH group the proportion above criterion increased from 1.8% for adolescents to 24.2% for young adults. That is, for the NH group, participation in high-noise activities was substantially higher for the young adults than their adolescent counterparts, a difference which was not evident for the HI group. In addressing the current research hypothesis, the analysis necessarily focused on quantitative data and group averages rather than individual data. The current results suggest a need for a more detailed investigation of the ways in which hearing impairment acts as a barrier to leisure participation, particularly during the transition from adolescence to adult life.

The excessive whole-of-life exposures of a significant proportion of participants suggest that public health messages about the risks of noise injury continue to go unheeded by many individuals. It was perhaps surprising that a number of individuals with hearing impairment were among the highly exposed cases, despite the fact that this group has regular and ongoing contact with hearing health professionals. An uncomplicated procedure for estimating the risk of NIPTS for individual clients with hearing impairment, based on readily available clinical information (e.g., HTLs, hearing aid characteristics, leisure activity and work profiles) would be useful in providing more objective and personalised risk-management advice to this group. The participation measure used in this study could be usefully incorporated into such a procedure. In this context, systematic data pertaining to the output of modern hearing aids in

dynamic, high-noise environments would be an important adjunct to the current findings, and these data are required for the development of a personalised risk estimate procedure for hearing aid wearers.

Hearing loss prevention campaigns may be more successful if greater emphasis was placed on reducing hazardous noise in leisure environments, rather than simply informing the individual about taking personal protective measures. In recent years the banning of tobacco smoking has been successfully implemented in eating and entertainment venues in many developed countries. This demonstrates that with perseverance social attitudes and behaviours *can* be shifted, resulting in very significant public health outcomes. As well as moderating the risk of leisure-noise-related hearing loss for attendees and employees, the reduction of noise in social venues would provide a more inclusive social environment for patrons with hearing impairment.

Limitations of the survey

When interpreting the results of this analysis, certain limitations of the sample, survey and methods should be considered. The participation rate was relatively low (only ~14% for the HI group). Furthermore, although not a convenience sample, both the HI and NH group showed a bias towards greater socio-economic advantage (i.e., based on a statistical indicator of socio-economic status ranking). The measurement window for the current study was whole-of-life and recall bias may, therefore, have affected some results. The test-retest reliability of the participation measure is currently unknown. As noted, the method of calculating exposure was a first-order approximation, based on data from the industrial context (ISO, 2013) and assuming non-impaired ears prior to exposure. It has been suggested that the risks relating to leisure noise may be different to those of occupational noise because of the differing physical

characteristics of the sound involved (Turunen-Rise et al., 1991). However, as the current research questions were addressed in group difference rather than absolute terms, the conclusions will be relevant even though the measure of exposure is an approximation.

CONCLUSIONS

At the time of writing, this is the first published study to estimate the whole-of-life noise exposure of young people with hearing impairment, using a measure of participation in everyday activities. The leisure profiles and whole-of-life noise exposure of adolescents with HI and NH were similar. For young adults, frequency of involvement in some activities was significantly lower for the HI group. Leisure activity diversity and whole-of-life exposure were also lower for the young adult HI group. The fact that almost a quarter of young adults with normal hearing reported noise exposure in excess of the noise-risk criterion is of concern. The more conservative behaviour reported by young adults with hearing impairment may be regarded as a positive finding with respect to noise risk; however, it could also signify disability-related social disadvantage. Targeting noise sources, rather than individual behaviours, may be a more effective approach to hearing loss prevention and would promote more accessible leisure environments for people with impaired and non-impaired hearing.

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