The Leisure-Noise Dilemma: Hearing Loss or Hearsay? What Does the Literature Tell Us?

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The authors undertook a review of the literature, focussing on publications describing the following: (1) Pure tone threshold data for adolescents/young adults; (2) Measurements/estimates of noise exposure from leisure activities; and (3) The relationship between hearing threshold levels (HTLs) and leisure-noise exposure. There is a large volume of published materials relevant to these topics, and opinion among authors regarding the relationship between leisure-noise exposure and HTLs varies significantly. At one extreme is the view that the effects of leisure-noise are minimal. The opposing belief is that as a direct result of leisure-noise exposure, significant HTL shifts and possibly significant hearing disability are occurring in a large (and increasing) proportion of young people. It has been claimed that behaviors relating to leisure-noise are "as threatening to young people's health as more traditional risk behaviors" (Bohlin & Erlandsson 2007, p. 55). This view has been reiterated by the popular media. This review revealed that while sufficient data confirm that some leisure pursuits provide potentially hazardous noise levels, the nature of the exposure–injury relationship for leisure-noise is yet to be determined. Specific information about the quality-of-life effects of threshold shift related to leisure-noise exposure is also lacking. The scope and limitations of a large sample of relevant publications and an overview of the methodological issues in this area of research are briefly presented. Considerations for future research are raised.

Key words: Adolescents, Hearing loss, Noise-induced, Leisure, Young adults.

(Ear & Hearing 2014;35;491–505)

INTRODUCTION

There is no doubt that exposure to noise (i.e., loud sound) of enough intensity over sufficient periods can result in temporary and permanent HTL shifts (Miller 1974; Mills 1975; Ylikoski et al. 2001; Zhao et al. 2010). Underlying pathological processes arising from noise exposure have been described in much detail (Nicotera et al. 2001; Wang et al. 2002; Kujawa & Liberman 2009; Makary et al. 2011; Op de Beeck et al. 2011). There appear to be a number of possible biological mechanisms (Henderson et al. 1993) and large interindividual variations in susceptibility to noise injury (Quaranta et al. 2001) that are still not fully understood. Auditory system damage may precede observable changes in the pure tone audiogram (Axelsson 1991; Axelsson et al. 1994; Smith et al. 2000; Kujawa & Liberman 2009; Jin et al. 2013). Carter et al. (1978; citing a study by Bienvenue et al. 1976) noted that noise has been shown to have a temporary effect on the loudness difference limen. West and Evans (1990) investigated frequency resolution abilities, reporting that participant groups "more exposed" to amplified music had wider bandwidths than less exposed groups under some conditions. Okamoto et al. (2011) reported a study of magnetoencephaolographic (MEG) responses of long-term users and nonusers of personal stereo players (PSPs). Both groups performed equally on standard audiometric evaluations (including pure-tone audiometry [PTA]); however, significantly broadened population-level frequency tuning in a group of long-term users under a specific listening condition was observed using MEG. Kumar et al. (2012) observed deterioration in temporal processing and speech processing abilities of individuals exposed to occupational noise, with HTLs better than 25 dB hearing level (HL) in the octave frequencies between 250 and 8000 Hz. Studies have also revealed an association between tinnitus and leisure-noise exposure, even in the presence of clinically unremarkable HTLs (Davis et al. 1998; Tin & Lim 2000; Holgers & Petterson 2005; Beach et al. 2013a).

In 1975, the International Organization for Standardization (ISO) published the first edition of its standard describing the statistical relationship between occupational noise exposure and noise-induced permanent threshold shift in people of various ages—ISO 1999 (ISO 1990). This description is based on data from a number of earlier, cross-sectional studies of workers' pure tone hearing thresholds. ISO 1999 provides the first reliable description of "noise exposure—hearing effect" (Williams 2011, p. 13) or the dose–response relationship between *occupational* noise exposure and pure tone threshold shift.

The association between noise exposure and noise injury is regarded as stronger for occupational noise than leisure noise (Hidecker 2008). It is believed, however, that technological advances, particularly the proliferation of PSPs, have led to dramatically increased leisure-noise exposure (Zhao et al. 2010; Levey et al. 2011), with a concomitant increase in risk for young people. In the 1960s, "the damaging effects of rock and roll music on hearing" (Rintelmann & Borus 1968, p. 57) were a new cause for concern. A large body of literature concerned with the possible relationship between leisure-noise exposure and hearing threshold shift has since amassed—however, there is still a lack of consensus about the extent of the risk. At one extreme, "….there is a concern we may be facing an epidemic of hearing impairment" (Agrawal et al. 2008, p. 1522). The opposing viewpoint is that the effects of leisure noise are "slight" (Carter et al. 1984).

The leisure-noise issue has received significant media attention (Carter et al. 1978; Smith et al. 2000; Schlauch & Carney 2011), with the popular press tending toward alarmist headlines, which Hétu and Fortin (1995) suggested denote a disapproving attitude toward particular leisure activities (e.g., rock music). A critical attitude is also discernible in some scientific publications. Maassen et al. (2001, p. 4), for example, commented that *A "techno freak" subjecting himself to loud music via a PCP* [personal cassette player] *endangers his ears in the same way as a worker in a steel factory using no ear protection.* Hétu and Fortin (1995) suggested that such assertions have received a wide and largely accepting audience. Further, leisure-noise

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exposure differs from occupational exposure with respect to the fact that individuals participate voluntarily in noisy recreational activities according to their own preferences. The restriction of preferred activities may be considered a legitimate "cost" (Hill 1965; Phillips & Goodman 2004), a factor that appears to have received relatively little attention in either public or scientific commentary on this issue.

In recent years, the National Acoustic Laboratories (NAL) has conducted a range of studies aiming to quantify leisure-noise sources and patterns of exposure, estimate community risk of noise injury from everyday nonwork activities and determine the prevalence of hearing threshold impairment in the younger Australian population. This review was undertaken with no previous intent to justify a particular position in the leisure-noise debate but rather with the aim of providing an objective frame of reference for disseminating recent NAL findings and for considering methodological "best practice" for ongoing research.

MATERIALS AND METHODS

An extensive literature review was conducted using commonly accessed Internet search methods (particularly, PubMed, Google Scholar, and MEDLINE) and scrutiny of the reference lists of peer-reviewed publications considered to be of high relevance. Search terms included *hearing threshold levels, leisure noise, music and hearing, recreational noise, prevalence of hearing loss, and personal stereo players*. Title selection and review were performed only by the first author. Only titles in English or with a translated abstract were considered. No meta-analysis was performed.

About 737 titles of interest (including peer-reviewed publications, referenced conference abstracts, and postgraduate theses) were identified in this review. It was evident that the number of publications relevant to this topic has increased steadily over the past 2 decades, as noted by other authors (Morata 2007; Zocoli et al. 2009). Figure 1 shows the number of titles identified by decade (relating to leisure-noise and hearing), from the 1940s until the end of the first decade of this century. It was beyond the scope of this review to fully appraise all of this material. Because several substantial reviews have been previously published (Mills 1975; MRC 1986; Clark 1991), more emphasis was placed on recent material. The total number of publications for review was also reduced as follows: articles that primarily addressed attitudes toward noise and descriptions of hearing loss prevention interventions or those providing hearing threshold data for very young children (particularly those obtained in screening programs) were eliminated. Articles pertaining primarily to the effects of noise exposure on otoacoustic emissions (OAEs) and articles relating specifically to occupational noise exposure (apart from musicians) were also excluded. Articles pertaining to professional classical musicians were excluded. Some articles containing data about employees in amplified music venues, however, were included, in view of the overlap between occupational and recreational exposure for rock and pop music. Articles relating to firearms use were excluded, on the basis that the serious threat of noise injury from firearms use (Clark 1991) is not controversial. A total of 265 articles were reviewed in full. The content of these key articles and supplementary details from another 145 topical abstracts (e.g., articles that were of interest but were not in the English language or could not be obtained) provided the basis for the following commentary.

RESULTS

Sound Pressure Level Measurement of Leisure-Noise Sources

Over 100 reports of this type were identified in this review. Results obtained using one or both of the following methods have typically been described:

1. Sampling the sound pressure level (SPL) using a sound level meter at a fixed position(s)—either in situ (at the activity site/venue) or in simulated laboratory conditions.
2. Measuring the SPL in real-life situations over a period, using individually worn noise exposure meters (dosimeters)—a technique that has become more feasible and more informative in recent years.

The difficulty in directly comparing the findings of different studies, which have used a variety of specific methods and metrics, is noteworthy. Weaknesses in the reported data for nonoccupational noise, such as inconsistencies in noise level

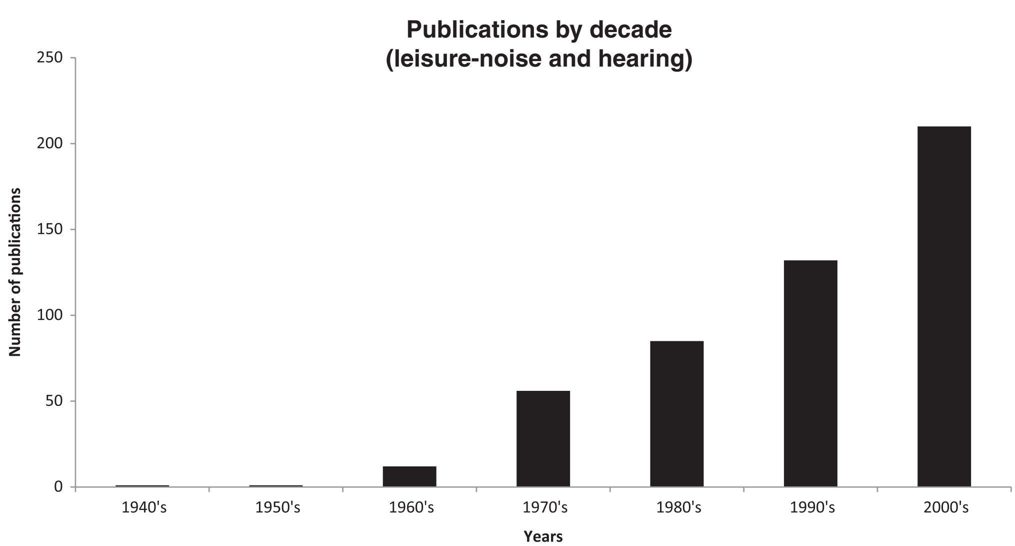

Fig. 1. Publications by decade (leisure-noise and hearing).

documentation, and the tendency to focus on the highest possible exposures during the noisiest activities have also been noted (Neitzel et al. 2004).

Early reports (dating from the 1960s) were reviewed by Mills (1975). Mills' article presents the SPLs of firecrackers, model aeroplanes, snow-mobiles, and firearms (including toy guns). A later review by Clark (1991) presented maximum SPLs of a variety of common recreational, domestic (e.g., food blender and vacuum cleaner), hobby, transportation, and firearm noise sources. In addition, Clark provided an overview of studies (conducted in the 1970s and 1980s) of rock concerts and the emerging "discotheque." Various reports of SPLs at rock music performances were subsequently published (Drake-Lee 1992; Yassi et al. 1993).

Clark (1991) also presented SPL data for early models of PSP, sourced from eight different publications (1972–1985). There have been at least three subsequent reviews of published PSP research, which provided output level data (Smith et al. 2000; SCENIHR 2008; Punch et al. 2011). Most recently, Portnuff et al. (2013) reported on PSP outputs, concluding that a "small but significant" percentage of PSP users reported exposure sufficient to increase the risk of noise injury. This conclusion is consistent with those of earlier reviews, although as noted by Portnuff et al., much higher estimates of risk have been given by some authors. For example, Levey et al. (2011) estimated that 58.2% of participants in their study (N = 189) exceeded recommended workplace exposure levels. Measurements in the Levey et al. study were, however, made in a single, high-background noise environment.

The level of noise emitted by children's toys has also been a subject of recurring interest. Subsequent to the reports described by Mills (1975), Yaremchuk et al. (1997) measured the level of 25 toys (e.g., bicycle horns, toy guns, toy tools, telephones, and musical instruments). More recently, Bittel et al. (2008) reported the output levels of 24 commercially available toys, noting that many toys exceeded recommended safety standards. Mahboubi et al. (2013) reported an experiment in which more than 200 toys were screened for loudness and 90 analyzed under controlled conditions. They concluded that acoustic trauma from children's toys continues to be a potential risk.

The level of noise generated by crowds at public events such as sports matches and rock concerts has received little attention but is also relevant. Opperman et al. (2006) described measures of stadium noise published in 1987 and observations of the contribution of crowd yelling and screaming to overall noise levels in their own study. Beach et al. (2013b) also make reference to crowd situations, such as sporting events, in their discussion.

In the last decade, SPL measures have been reported for a range of other leisure activities, such as electronic arcade games (Mirbod et al. 1992), car stereos (Ramsey & Simmons 1993), air shows (Pääkkönen et al. 2003), Korean karaoke singing (Park 2003), aerobics classes (Torre & Howell 2008; Beach & Nie 2014), auto racing (Rose et al. 2008; Kardous & Morata 2010), indoor hockey (Cranston et al. 2013), and marching bands (Jin et al. 2013). Results of some of these studies indicate that when typical activity durations are taken into account, the risk to patrons may not be significant (Ramsey & Simmons 1993; Pääkkönen et al. 2003; Rose et al. 2008). Other studies indicate that typical participation in some environments may place individuals at risk, for example, aerobics classes, stock car racing tracks, indoor hockey arenas, and karaoke singing venues.

"Daily life" measures, obtained using individual dosimetry, have been reported by several authors (Neitzel et al. 2004; Flamme et al. 2012; Beach et al. 2013b). In these studies, amplified music stands out as a concerning source of leisure-noise exposure. Beach et al. (2013b) described a contemporary inventory, referred to as the "NOISE" (nonoccupational incidents, situations, and events) database, in which over 500 dosimetry samples obtained since 2008 have been indexed and categorized for general reference. A number of the loudest samples are contained under the categories "attendance at entertainment venues" (which include karaoke events, nightclubs, dance clubs, and discos) and "arts and cultural activities" (which include live music performances, popular music concerts, and music festivals).

Overall, there is reasonable agreement among authors that some leisure activities (particularly shooting and amplified music listening) provide SPLs that would be of safety concern in industrial settings (Tambs et al. 2003; Zhao et al. 2010). Although the levels of some leisure activities are analogous to those encountered in occupational settings, it is important to reiterate that the damaging effects of noise depend not only on intensity but also on the duration and pattern of exposure and possibly on other individual susceptibility factors. To date, risk estimates for leisure-noise exposure have been based on dose–response relationships observed in the industrial setting (e.g., ISO 1999, 1990; ISO 1999, 2013), which assume continuous 8 hr daily exposure over many years (Hétu & Fortin 1995). Strasser et al. (2003) cautioned that rating sound exposures by energy equivalence alone can lead to very misleading assessments of their actual physiological costs.

Apart from the fact that noise exposure during leisure is typically less frequent and intense than that encountered in the workforce, there is also the possibility that nonindustrial sources (because of their unique physical characteristics) may have distinctive effects on the auditory system. Most music, for example, has a greater variation in spectral content and intensity and a greater spread of energy over time, compared with typical industrial noise sources (Turunen-Rise et al. 1991). It has been suggested that the intermittent nature of music may reduce the risk of noise-induced hearing loss (NIHL) occurring (Jin et al. 2013), and that exposure to some types of moderate-level noise may have a "conditioning" or protective effect on the cochlea (McFadden et al. 1997; Niu & Canlon 2002). The "heavy metal" genre, however, has been reported as more similar in effect to industrial sources (Strasser et al. 1999).

Studies Exploring the Relationship Between Leisure-Noise Exposure and HTL

Obviously, it is ethically impossible to determine the noise–injury relationship in human subjects via direct experimental means. The following section describes the six main methodological approaches that have been applied to this research question. The main studies identified in each of these categories are listed in Tables 1–6.

Preexposure/Postexposure Assessments • The effects of leisure-noise exposure have been investigated experimentally using preexposure and postexposure audiometry (and/or other measures, such as OAEs), to look for evidence of postexposure shift, then recovery of HTLs (i.e., temporary threshold shift [TTS]). Table 1 lists the methods and findings of 19 investigations of this type, conducted from the late 1960s to date.

TABLE 1. Studies of TTS

Authors	Participants	Method/Noise Source	Conclusion
Rintelmann and Borus (1968)	N = 52 United States (U.S.) 18–20 yrs	PTA (pre/post live rock music)	Concern seems unwarranted
Reddell and Lebo (1972)	N = 43 U.S. rock musicians Mean age 22 yrs	PTA (pre/post hard rock music)	TTS observed in musicians and some listeners
Axelsson and Lindgren (1978)	N = 83 Swedish pop musicians and listeners	PTA (pre/post pop music)	Less TTS in musicians than listeners
Lindgren and Axelsson (1983)	N = 10 Swedish teenagers	PTA (pre/post 10 min laboratory stimuli)	Noted differences in TTS with musical vs. nonmusical stimuli
Lee et al. (1985)	N = 16 U.S.	PTA (pre/post 3 hr PCP exposure)	6/16 showed TTS. All recovered after 24 hr
Clark and Bohne (1986)	N = 6 U.S. rock concert attendees	PTA (pre/post rock concert)	5/6 showed TTS
Swanson et al. (1987)	N = 20 U.S. undergraduate students	PTA, tympanometry, acoustic reflex thresholds (pre/post laboratory noise and music)	Relationship found between TTS and music preference (greater for disliked music)
Hellström et al. (1998)	N = 21 Swedish PCP/speaker listeners	Bekesy (pre/post 1 hr of PCP use)	Most had only “discrete” TTS, despite levels of 91–97 dB
Drake-Lee (1992)	N = 5 United Kingdom (U.K.) heavy metal players 25–37 yrs	PTA (pre/post rock concert)	TTS noted in all but one musician (who used PHP)
Yassi et al. (1993)	N = 22 Canadian 18–40 yrs	PTA (pre/post rock concert)	81% showed TTS of 10 dB or more
Vittitow et al. (1994)	N = 12 U.S.	PTA (pre/post music and cycling)	Greater TTS for noise and exercise condition than noise alone
McCombe et al. (1995)	N = 18 U.K. motorcyclists	PTA (pre/post 1 hr motorcycle ride)	Significant TTS found at 0.25–2 kHz
Strasser et al. (1999)	N = 10 German 18–30 yrs	PTA (pre/post laboratory music vs. industrial and white noise)	Demonstrated TTS with all sources. Least effect with classical music. Industrial noise and heavy metal music showed similar effect
Mazelova et al. (2001)	N = 12 Czech 18–25 yrs	PTA, Bekesy high resolution, OAE (pre/post laboratory amplified music)	Demonstrated changes in all measures except gap detection
Nassar (2001)	N = 28 U.K. Mean age 21 yrs	PTA (pre/post aerobics class)	Exposed group showed TTS, control group slightly improved HTLs (practice effect?)
Sadhra et al. (2002)	N = 14 U.K. university student bar employees 20–40 yrs	PTA (pre/post bar/discotheque music)	13/14 showed TTS
Emmerich et al. (2002)	N = 34 German 18–24 yrs	PTA and AEF (pre/post discotheque music)	TTS found in all subjects and AEF latency shifts
Opperman et al. (2006)	N = 29 U.S. 17–59 yrs	PTA (pre/post concert-amplified music)	64% of unprotected listeners showed TTS, 27% of those using earplugs
Keppler et al. (2010)	N = 21 Belgian 19–28 yrs	PTA and OAE (pre/post high-level MP3 pop/rock music)	Changes in PTA and TEOAE in exposed group. No significant changes in DPOAE
Tam et al. (2013)	N = 12 Australian 19–28 yrs	PTA and OAE (pre/post MP3 music)	Significant increase in 6 kHz HTL and significant reduction in some DPOAE and TEOAE amplitudes post exposure

AEF, auditory evoked magnetic field; DP, distortion product; OAE, otoacoustic emission; PCP, personal cassette player; PHP, personal hearing protector; PTA, pure-tone audiometry; TE, transient evoked; TTS, temporary threshold shift.

TABLE 2. Retrospective cohort studies

Authors	Participants	Exposure Source	Findings
Hanson and Fearn (1975)	N = 505 U.K. students	Pop music	PTA: Small but statistically significant difference between case and controls
Fearn (1981)	N = 367 U.K. school children	Amplified pop music	PTA: statistical analysis not presented (differences in order of a few decibels)
West and Evans (1990)	N = 60 U.K. 15–23 yrs	Amplified music	Bekesy audiometry and frequency resolution: “Trend” toward wider bandwidths in the exposed
Jorge Junior (1993) (cited by Zocoli et al. 2009)	N = 958 Brazilian teenagers	PSPs	PTA: no significant differences
Schmidt et al. (1994)	N = 133 Dutch Music students and controls	Classical music	PTA: no significant difference
Meyer-Bisch (1996)	N = 1364 French ~15–25 yrs	Discotheques, PSPs, and rock concerts	PTA: no significant differences for discotheque exposure. Small (~2–4 dB) but significantly significant differences comparing controls and the “intensively” exposed for PSP and rock concert exposure
Mostafapour et al. (1998)	N = 50 U.S. college students	PSPs	PTA: no significant differences
Peng et al. (2007)	N = 120 Chinese University students	PSPs	PTA: statistically significant differences (~3–5 dB) reported

N refers to total number of participants (case and controls).
PSPs, personal stereo players; PTA, pure-tone audiometry.

Many of the studies listed in Table 1 reported positive findings. However, the relationship between TTS and permanent threshold shift is still debated (Quaranta et al. 2001; Zhao et al. 2010). Consequently, although studies of this type are of interest, they do not provide conclusive information about the lasting effects of leisure noise on hearing thresholds. It is also possible that even when HTLs recover, lasting physiological changes have nevertheless occurred.

Retrospective Cohort Studies • In a number of investigations, HTLs and/or other indicators (e.g., OAEs) have been examined in groups of individuals voluntarily exposed to specific leisure-noise sources versus similar, nonexposed (control), participants.

MRC (1986) noted that earlier studies of this type revealed differences in hearing thresholds of no more than a few decibels in noise-exposed versus nonexposed groups. Findings of

TABLE 3. Cross-sectional studies (n < 500) that include comment on leisure-noise exposure

Authors	Participants	Assessment Method	Effect of Leisure-Noise?
Carter et al. (1978)	N = 231 Australian university students	PTA; survey—occupational and recreational exposure	No
Lees et al. (1985)	N = 60 Canadian 16–25 yrs	PTA; survey—occupational and recreational exposure	Yes. 40% prevalence rate of hearing loss (but insufficient to cause hearing disability)
Ahmed et al. (2007)	N = 24 Canadian university students	PTA (PSP users only); survey	No evidence of early hearing loss
Kim et al. (2009)	N = 490 Korean adolescents 13–18 yrs	PTA Interview (PSP use)	No relation between HTL and daily use; however, 4000 Hz “elevated” in 24 participants with highest exposure
Martínez-Wbaldo et al. (2009)	N = 214 Mexican teenagers	PTA; survey—noisy activities at school and leisure	“Moderate” association between leisure noise and hearing loss. 20% prevalence rate of loss
Zocoli et al. (2009)	N = 245 Brazilian 14–18 yrs	PTA; survey—noisy leisure activities	No
Le Prell et al. (2011)	N = 56 U.S. college students	PTA; survey—risk factors	“Statistically reliable relationship” between HTL and PSP use in males only

PSP, personal stereo player; PTA, pure-tone audiometry.

TABLE 4. Cross-sectional studies (n ≥ 500) that include comment on leisure-noise exposure

Authors	Participants	Assessment Method	Effect of Leisure-Noise?
Strauss et al. (1977)	N = 1300 German	PTA? (German article)	No
Axelsson et al. (1981)	N = 538 Swedish 17–20 yrs	PTA	No
Carter et al. (1982)	N = 944 Australian 16–20 yrs	PTA; ENT exam	No
Buffe et al. (1986) Article in French, cited by Petrescu (2008)	N = 51,726 French 18–25 yrs	PTA; medical exam; noise history	No real correlation between music exposure and HTL. (Noted professional DJs had higher HTLs).
Costa et al. (1988)	N = 2264 Swedish 7, 10, and 13 yrs	PTA screen (no exposure data or tympanometry)	Yes, on the basis that HF loss is more common, and males more affected than females
Axelsson et al. (1994)	N = 500 Swedish 18 yrs	PTA	No
Haapaniemi (1995)	N = 687 Finnish 6–15 yrs	PTA; ENT exam; survey	No
Cone et al. (2010)	N = 6591 Australian school children yrs 1 and 5	PTA screening	Reported PSP use as a risk factor, but most significant factor = NICU admission
Twardella et al. (2011) (German)	N = 2240 German students grade 9	PTA; medical exam; questionnaire	Nonoccupational risk factors identified: firearms, chain saws, and power tools
Carter (2011)	N = ~1400 Australian 11–35 yrs	PTA; interview; questionnaire	No (preliminary analysis)

DJ, disc jockey; ENT, ear, nose and throat specialist; HF, high frequency; NICU, neonatal intensive care unit; PSP, personal stereo player; PTA, pure-tone audiometry.

studies published in the following decade are similarly undramatic (Schmidt et al. 1994; Meyer-Bisch 1996; Mostafapour et al. 1998). One of the largest studies (N = 958) to date (Jorge Junior 1993) revealed no significant differences between HTLs of PSP users and nonusers. More recently, Peng et al. (2007) reported significant differences in HTLs for conventional and extended range audiometry (10 to 20 kHz) between PSP users and nonuser controls (N = 120/30 respectively). Peng et al. concluded that 34 out of 240 ears tested (14.1%) showed evidence of hearing loss.

Cross-Sectional Studies of HTL • A number of cross-sectional audiometric studies similar in size to the cohort studies described earlier have been undertaken. A summary of seven studies with N < 500 is listed in Table 3.

Among these studies, there are an equal number of positive and negative findings. Relatively small sample sizes and use of convenience samples in smaller cross-sectional and experimental studies may affect generalizability of results. In addition, it seems possible that experimental work of this type could be subject to publication

TABLE 5. Longitudinal studies

Authors	Participants	Assessment Method	Effect of Leisure-Noise?
Roche et al. (1977, 1979, 1982)	N = 1100 United States Main sample 6–18 yrs	PTA over 5 yrs; survey; dosimetry	No significant associations between HTL and noise exposure scores
Carter et al. (1984)	N = 141 Australian 10–12 yrs (at first assessment)	PTA × 2 (retest 6–8 yrs after baseline)	No significant HTL shifts
Biassoni et al. (2005); Serra et al. (2005)	N = 173 Argentine 14–17 yrs	PTA annually for 4 yrs	Significant downward shift in HTLs for frequencies above 8000 Hz
Jin et al. (2013)	N = *698* U.S. university band members ≤25 yrs	PTA; OAE; survey (retest 3–4 mo after baseline)	No significant bilateral HTL shifts reported

OAE, otoacoustic emission; PTA, pure-tone audiometry.

TABLE 6. Cross-sectional surveys using audiometric configuration (notch) as indicator

Authors	Participants	Assessment Method	Findings
Guild (1950)	Unknown United Kingdom (U.K.)		"Abrupt" audiometric configurations not always associated with impulse noise exposure
Hinchcliffe (1959)	N = 100 U.K.	PTA; ENT exam; questionnaire; risk factors	Poorer mid-high frequency HTLs in males—associated with small arms use
Cozad (1974)	N = 18,600 U.S. school students	PTA (no exposure data)	Cite audiometric configuration (hearing loss above 3000 Hz) as possible evidence of NIHL
Axelsson et al. (1981)	N = 538 Swedish 17–20 yrs	PTA	15% showed some hearing loss. Refers to "dip" at 6 kHz—but no correlation with leisure-time activities
Rytzner and Rytzner (1981)	N = 14,391 Swedish 7, 10, and 13 yrs	PTA screen; ENT follow-up	Small occurrence (4 kHz "dip") associated with exposure in approximately 200 cases
Molvaer et al. (1983)	N = 1474 Norwegian 20–80 yrs	PTA; ENT exam; questionnaire	6 kHz "dip" noted, even in youngest participants. Assumed noise related
Haapaniemi (1995)	N = 687 Finnish 6–15 yrs	PTA; ENT exam; questionnaire	8.3% occurrence. Cites several possible factors
Holmes et al. (1997)	N = 342 U.S. 10–20 yrs	PTA screen; six-item questionnaire	6 kHz "dip" associated with firearms use
Mostafapour et al. (1998)	N = 50 U.S. 18–30 yrs	PTA; speech discrimination test	Found only one case of "notch" at 6 kHz
Niskar et al. (2001)	N = 5249 U.S. 6–19 yrs	PTA (NHANES III data) (no exposure data)	12.5% estimated to have a "notch (NITS)"
McBride and Williams (2001)	N = 357 U.K. electricity employees	Bekesy audiometry; questionnaire	49% determined to have a "notch"—no association with NIHL risk factors
Rabinowitz et al. (2006a)	N = 2526 U.S. 15–25 yrs	PTA (limited exposure data)	Almost 20% had "notch"— rate constant over 20 yr interval. Likely related "at least in part" to noise exposure
Nondahl et al. (2009)	N = 2395 U.S. 43–84 yrs	Compared algorithms using previous data (Beaver Dam study)	"Notches" noted in the absence of noise exposure history. Poor agreement among four different algorithms
Osei-Lah and Yeoh (2010)	N = 149 U.K. outpatients 19–91 yrs	ENT outpatient assessment	39.6% exhibited "notches" not attributable to noise or other risk factors
Schlauch and Carney (2011)	N = 5089 U.S. 6 to 19 yrs	PTA (NHANES III data) compared test and retest data and computer-simulated audiograms	Similar prevalence of "notches" in actual and simulated audiograms
Jin et al. (2013)	N = 698 U.S. marching band members and controls ≤25 yrs	PTA; OAE	Noted transitory behavior of "notches" on multiple retests
Twardella et al. (2013)	N = 1843 German adolescents ~15 to 16 yrs	PTA	2.4% prevalence of "notches"

ENT, ear, nose, and throat specialist; NHANES, National Health and Nutrition Examination Survey; NIHL, noise-induced hearing loss; NITS, noise-induced threshold shift; OAE, otoacoustic emission; PTA, pure-tone audiometry.

bias, that is, studies with positive results are more likely to be accepted for publication than those with null or negative results.

Results of a number of larger cross-sectional studies (N = ~500–2000) have also been reported. Ten examples identified in this review are listed in Table 4. Only two of these studies suggest an association between HTLs and leisure-noise exposure (Costa et al. 1988; Cone et al. 2010). Costa et al. (1988) reported a higher incidence of high-frequency hearing loss in males than females and speculated that on the grounds that males typically engage in noisier activities than females, these high-frequency losses may thus be noise induced. Costa et al., however, noted that methodological issues, such as cerumen occlusion or collapsing canals, may have affected findings. Apparently, information regarding participant noise exposure was not obtained in this investigation.

Cone et al. (2010) tested the hearing of a large group of elementary school children (N = 6591). Sensorineural hearing loss was identified in 0.88% (55 of a total of 6581 children assessed). The use of PSP players was reported to be significantly higher in the group identified with hearing loss compared with the group with normal hearing. The greatly disparate number of affected versus nonaffected cases, however, may cast doubt on Cone et al.'s conclusion that PSP use may be a risk factor for hearing loss. Further, Cone et al. noted that of the children reported to use PSPs, there was no difference in the reported hours of use per day, or parents' reports of playing the "stereo too loud" in the normally hearing versus sensorineural hearing loss groups. Overall, the available evidence from the larger cross-sectional studies identified in this review does not suggest a compelling association between leisure-noise exposure and HTLs.

Longitudinal Studies • The present review identified only four studies providing serial audiometric data (with various retest intervals) and leisure-noise exposure data for young (mainly teenage) subjects. The details of these studies are listed in Table 5.

A series of reports by Roche et al. (1977, 1979, 1982) described a 5-year longitudinal hearing survey (Fels study). Roche et al. (1979) reported no statistically significant associations between noise scores (derived from noise exposure histories) and HTL. For group mean threshold data, however, significant differences were observed for groups with particular exposures (specifically, power tools, Hi Fi, loud TV, and exposure to farm machinery) relative to groups reporting no exposure. Roche et al. concluded that a longer surveillance period was required for a more effective analysis to be made. Carter et al. (1984) reported no significant shift in HTLs over a 6- to 8-year test period. Biassoni et al. (2005) and Serra et al. (2005) reported a significant downward shift in HTLs, confined to test frequencies above 8000 Hz. However, the lack of normative data for the extended high-frequency range makes this finding difficult to interpret in isolation. Further, Schmidt et al. (1994) suggested that intersubject variations are greater in extended range audiometry compared with conventional audiometry, and that aging effects may be present for the very high frequencies even in relatively young people. Schmidt et al. concluded that high-frequency audiometry cannot serve as an early indicator of the traumatic effects of noise. Jin et al. (2013) studied the hearing of a group of U.S. university marching band members and age-matched controls. The period between baseline test (preband camp) and follow-up (retest) was 3 to 4 months, with subsequent assessment annually (during band camp). No significant bilateral hearing threshold shifts were reported

Population Surveys of HTL • Several retrospective analyses of HTL data from large population surveys have been published (Niskar et al. 1998; Niskar et al. 2001; Hoffman et al. 2010; Shargorodsky et al. 2010; Henderson et al. 2011). The HTL data analyzed were obtained in the U.S. National Health and Nutrition Examination Surveys (NHANESs), which provide ongoing, broad health surveillance (Flamme et al. 2012). NHANES data sets and experimental protocols are publicly available (Centers for Disease Control and Prevention 2013) and contain HTL values for large numbers of young participants (e.g., N = ~5000 for 6- to 19-year-old cohorts of NHANES III).

Niskar et al. (1998, 2001) were the first to publish analyses of NHANES III data (1988–1994) with the aim of estimating the prevalence of hearing loss in the young U.S. population. Niskar et al. reported that "14.9% of U.S. children have low-frequency or high-frequency hearing loss of at least 16 dB hearing level in one or both ears" (p. 1071). Subsequently, the same authors (Niskar et al. 2001) published an alternate analysis of the same data, concluding that "12.5% of U.S. children aged 6 to 19 years (approximately 5.2 million) are estimated to have noise-induced threshold shift (NITS) in one or both ears," and stated that *These findings suggest that children are being exposed to excessive amounts of hazardous levels of noise, and children's hearing is vulnerable to these exposures* (p. 40). Subsequently, Shargorodsky et al. (2010) published an analysis of the same NHANES III data, and later NHANES data (2005–2006) reporting a prevalence rate of hearing loss of 19.5% among 6- to 19-year-olds for the 2005 to 2006 cohort. As Schlauch and Carney (2011) acknowledge, as the first of their kind, the publications of Niskar et al. are important. However, there are important limitations that cast doubt of the appropriateness of these prevalence estimates. These factors are explained in detail later in this review (see Discussion section).

Hearing survey data from larger population health studies have also been used to look for changes in hearing loss prevalence in populations over time, testing the assumption that technological and social changes have resulted in increased leisure-noise exposure. The conclusions reported are inconsistent. For example, Hoffman et al. (2010) compared National Health Examination Survey I 1959 to 1962 with NHANES 1999 to 2004 data, reaching the conclusion that *Americans hear as well or better today compared with 40 years ago* (Hoffman et al. 2010, p. 725). Shargorodsky et al. (2010) compared NHANES III 1988 to 1994 with NHANES 2005 to 2006 data, concluding that the prevalence of hearing loss among U.S. adolescents aged 12 to 19 years *increased* from 14.9% in 1988 to 1994 to 19.5% in 2005 to 2006. The authors note, however, that the "majority of the hearing loss was slight" (Shargorodsky et al. 2010, p. 775), and most cases were unilateral. Schlauch and Carney (2012) suggested that methodological differences between the two study periods (e.g., different tester qualifications) could affect the estimated hearing loss prevalence. Using slightly different exclusion criteria and definitions of pure-tone average, Henderson et al. (2011) compared the same NHANES data sets as Shargorodsky et al., reporting no increase in prevalence.

Several reports have also been published comparing the hearing thresholds of other cohorts and these also show mixed conclusions. Persson et al.'s (1993) analysis of audiograms of 18- to 19-year-old Swedish military conscripts (obtained between 1969 and 1977) suggested improvement in hearing thresholds across time, which, it was speculated, may reflect improvements in general otological management after the 1950s to 1960s. Axelsson et al. (1994) referred to a 1988 report on Swedish military conscripts (Borchgrevink 1988), which concluded that the incidence of hearing loss had "doubled" since 1981. Rabinowitz et al. (2006b) reported that U.S. Army data from a similar period (1974–1989) showed a decrease in prevalence of hearing loss of army recruits. To date, studies of prevalence trends are few, and whether the rate of NIHL is on the rise seemingly "remains controversial" (Rabinowitz et al. 2006b, p. 369). Further, Lutman and Davis (1994) emphasized that, given all the possible factors involved, it would generally be unsurprising to find substantial variation between different sets of audiometric results, even when comparing large studies (where only small differences would be otherwise expected from statistical uncertainty).

Case Reports • The current review identified only two articles containing case reports. First, McMillan and Kileny (1994) presented a single case study of hearing loss documented in a child exposed to an impulse noise from a bicycle horn. The second article, Brookhouser et al. (1992) includes five case studies of young people diagnosed with NIHL (NIHL was assumed on the basis of exposure history provided by the child or others and the absence of other plausible etiologies).

DISCUSSION

This review confirmed that PTA has remained the "test of choice" in leisure-noise research. However, Schlauch and Carney (2011, 2012) and others (Green 2002) have identified notable limitations in (1) the use of audiometric surveys in general and (2) the particular analytical techniques used by some authors in this field of inquiry (Niskar et al. 1998, 2001; Shargorodsky et al. 2010). Nevertheless, it was evident that the publications of Niskar et al. (1998, 2001) and Shargorodsky et al. (2010) are much cited in support of the position that NIHL in young people is a significant problem (e.g., Chung et al. 2005; Tharpe & Sladen 2008; Kim et al. 2009; Shah et al. 2009; Levey et al. 2011; Mahboubi et al. 2013). It therefore seems appropriate to review the main issues of concern. Seven main factors that have a significant effect on both the interpretation of results of individual studies and the extent to which the results of different studies can be meaningfully synthesized were identified in this review. Each of these factors is described in the following section.

Inherent Imprecision of PTA

As Schlauch and Carney (2012) emphasized, although PTA has been considered the "gold standard" for assessing hearing threshold sensitivity (Shargorodsky et al. 2010), it is subject to variability due to calibration issues, test protocol, test–retest reliability, test environment, tester, and participant factors (e.g., motivation). These factors become critical when attempting to identify incipient, or minimal, hearing loss (Schlauch & Carney 2012), and where comparisons are made between data sets.

Influence of "Pass–Fail" Criterion

In the clinical context, hearing thresholds better than 20 dB are generally treated as within "normal" limits (Lutman & Davis 1994). However, the cutoff criterion (or "fence") between "normal hearing" and "hearing loss" has not been standardized among scientific investigators (Mehra et al. 2009; Shargorodsky et al. 2010). Many different criteria have been applied (some involving averaging of HTLs), generally without any clearly articulated justification. In estimating the prevalence of hearing loss within a population, the lower (i.e., stricter) the criterion adopted, the higher the reported prevalence (Mehra et al. 2009). A study by Lees et al. (1985), listed in Table 3, is a case in point. In this analysis, a very strict criterion was used (any HTL ≥ 10 dB HL) with a resulting reported prevalence rate (40%) that far exceeds other estimates.

Reference HTL Data

With respect to hearing loss criterion, it is also important to be mindful that "audiometric zero," is not an absolute but must be inferred statistically from specific and adequate population data (Corso 1963; citing Hirsch 1952). Such population data are presented in ISO 7029 (ISO 1984). General discrepancies between measured group thresholds and ISO 7029 data (ISO 1984) have been reported by a number of investigators (Guest et al. 2012). If the ISO 7029 reference levels are not, in fact, typical of the general population, overestimation of prevalence will result, that is, the underestimation of "audiometric zero" will contribute to an assumption that experimental group data are intrinsically poorer than would otherwise be deduced. "Low fence" estimates of hearing loss will also be additive with overly restrictive audiometric norms in this respect. In reviewing the results of audiometric surveys from various countries, Borchgrevink (2003) concluded that the median HTLs of any group of 18- to 20-year-olds are not 0 dB, but in the order of +5 dB for most frequencies (0.25–8 kHz). This assertion is supported by recent Australian data (Williams et al. 2014). Schlauch and Carney (2011) noted that NHANES III (1988–1994) median HTLs are greater (i.e., worse) than 0 dB HL at each frequency and suggested that this is not surprising, given that NHANES participants were not as stringently selected as those for studies contributing to ISO 7029. Reference databases that are carefully obtained and relevant to specific research target populations (e.g., adolescents and young adults) are currently lacking (ISO 2013).

Baseline PTA

Given the uncertainties around reference audiometric data, NITS can really only be ascertained when preexposure (baseline) audiometric results are available. The majority of hearing surveys have not included baseline audiometry (Holgers & Petterson 2005). Nevertheless, the terminology NITS (or noise-induced permanent threshold shift) has been used by some authors (Niskar et al. 2001). In the absence of baseline data, this is presumptive (Meinke & Dice 2007) and may be misleading. It is also incorrect to assume that every individual starts with a preexposure 0 dB HL "baseline" even in the absence of other risk factors for hearing loss, as evidenced in ISO 7029 data.

Audiometric Configuration

It has been clinically observed that subsequent to noise exposure, audiograms often show a frequency-specific hearing loss—typically in the 2 to 8 kHz region (Patuzzi 1992) commonly referred to as a "noise notch." The criterion used to identify a notch varies among investigators (Mostafapour et al. 1998; Rabinowitz et al. 2006a) and determines the reported prevalence of its occurrence (Nondahl et al. 2009). Nondahl et al. (2009) systematically compared four notch "algorithms" (Coles et al. 2000; Dobie & Rabinowitz 2002; McBride & Williams 2001; Hoffman et al. 2006), observing poor agreement across criteria. Bilger (1976, p. 458) also cautioned that while group average notch data may be of interest, it must be ascertained whether a "typical" notch profile can also be systematically identified in noise-exposed individuals.

It is clear from the literature that, regardless of criterion used, not all individuals identified as having a noise notch report a positive history of noise exposure, and neither do all individuals reporting a positive history of noise exposure have a notch configuration (McBride & Williams 2001; Nondahl et al. 2009; Osei-Lah & Yeoh 2010). There is also evidence that "dips" at 4 or 6 kHz may have etiological factors apart from noise exposure (e.g., genetic, viral infections, otitis media, skull trauma, and ototoxic drugs; Sataloff 1980; Haapaniemi 1995). Klockhoff and Lyttkens (1982) presented 30 cases of children with a 4 kHz "dip," none of whom had a history of noise exposure.

Reliance on "noise notches" occurring at 6 kHz is particularly problematic. Threshold elevation at 6 kHz may occur due to error in calibration reference values (Lutman & Qasam 1998; McBride & Williams 2001; Schlauch & Carney 2011). Even small systematic errors such as these have a significant effect on the estimates of occurrence of notched audiograms. Schlauch and Carney (2011) re-analyzed NHANES data (using similar inclusion criteria to Niskar et al. 2001). They concluded that systematic threshold error at 6 kHz (for all age groups) and 8 kHz (for younger participants) were very likely to have influenced findings. Despite all these difficulties, a number of reporters on leisure-noise effects have used the noise notch as a "proxy" (Green 2002) indicator of NIHL. Examples of some studies using the noise notch as a metric, and others critiquing the use of the notch are listed in Table 6.

Apart from the scientific limitations of the use of the notch as a metric, it is also concerning that some articles confidently cited noise notch presence as evidence of NIHL, yet provided no substantiating data regarding participants' actual leisure-noise exposure (e.g., Cozad et al. 1974; Niskar et al. 2001).

Confounding Variables • For meaningful estimates of NITS to be made, all possible risk factors for hearing loss must be taken into account (Engdahl et al. 2005), and HTL data for cases in which confounding variables exist must be excluded from the data analysis. Some confounding factors are immediate and can be observed at the time of assessment (e.g., cerumen occlusion and middle ear dysfunction), whereas others must be identified through careful history taking (e.g., prenatal exposure to disease, ototoxic drug exposure, family history, and head/ear trauma). There is also increasing evidence that other agents, such as tobacco (Ferrite & Santana 2005) and solvents (Campo & Lataye 2000), may represent significant risk factors for hearing loss.

Achieving the appropriate suite of exclusions is important, but challenging, as Schlauch and Carney (2012) demonstrate well. Obtaining an adequate case history is time consuming and subjective, because it relies on the recollection of the participant or informant. Further, a stringent set of exclusion criteria has the advantage of removing extraneous causes of variation but introduces the disadvantage of decreased statistical power in particular strata (Lutman & Davis 1994). There are insufficient test items in some data sets for strong exclusion criteria to be applied, which weakens the usefulness of the data in determining NIHL. NHANES III, for instance, did not include otoscopy or pure tone audiometric bone conduction testing in its protocol, a point that is clearly acknowledged by Niskar et al. (1998) and Shargorodsky et al. (2010). Tympanometry was included in the NHANES III protocol, but Niskar et al. and Shargorodsky et al. apparently did not use the available results as an exclusion criterion in their analyses. The NHANES III data set also lacks information about the noise exposure history of participants. Although the 2005 to 2006 NHANES protocol included a detailed questionnaire including probes on firearms use, occupational and nonoccupational noise exposure, Shargorodsky et al. make only limited reference to this information in their commentary.

To demonstrate the importance of such analysis decisions, Schlauch and Carney (2012) re-analyzed NHANES III and NHANES 2005 to 2006 data using the same criteria for hearing loss as Niskar et al. (1998) and Shargorodsky et al. (2010) but applying various exclusion criteria. They clearly demonstrated how criterion for hearing loss and exclusion criteria interact to determine the estimated prevalence of hearing loss overall. Schlauch and Carney also highlighted the work of Henderson et al. (2011), who analyzed the same data for teenage participants as Shargorodsky et al. but applied different exclusion criteria and a different criterion for hearing loss. Henderson et al. reported a lower prevalence of hearing loss than Shargorodsky et al. However, it is difficult to ascertain whether exclusions used, or the definition of hearing loss, contributed more to the difference in prevalence estimates (Schlauch & Carney 2012).

It is also noteworthy that the analysis by Schlauch and Carney (2012) showed a higher percentage of 6- to 8-year-old participants met the criterion for hearing loss than 6- to 11-year-old children (18% versus 16.3%, respectively). Given that children as young as 6 to 8 years are unlikely to have any significant risk for NIHL, this finding casts further doubt on the assumption that the observed hearing losses in these young cohorts are attributable to noise exposure.

General Comments

There are extensive data indicating that significant loud-noise exposure occurs in a range of leisure situations (in particular, when using firearms and attending rock concerts, nightclubs, and similar venues). However, there still appears to be insufficient consistent, empirical evidence to support the position that pure tone hearing loss, which is causally related to leisure-noise exposure, is either very widespread among young populations or is increasing over time. Much of the past research provides little insight into the lasting effects of leisure-noise exposure (e.g., experimental TTS studies, retrospective analyses of population data) and there is a dearth of more revealing studies (e.g., longitudinal studies). Some of the earlier literature provides insufficient detail for useful retrospective interpretation. The limitations of PTA as a metric have not always been acknowledged. Case studies account for a large proportion of published material across a wide range of disciplines; however, the scarcity of case studies in the leisure-noise literature (Luxon 1998) is noteworthy. Although as a research methodology case studies are regarded as at the lower end of the evidence-based research pyramid, they can add depth of understanding to enquiries that large sample approaches do not provide and may help "close in" on real-life situations (Flyvbjerg 2006). Perhaps most importantly, results from different studies using similar methods, or even using the same data, are not in good agreement.

Based on the evidence available for occupational noise exposure, some commentators have seemingly overstated the likely longer-term effects of leisure-noise exposure. For example, Niskar et al. (2001) reported that children were found to have "moderate to profound NITS" and that "With continued harmful noise exposures, the threshold shift at 3, 4 or 6 kHz increases in severity…" (Niskar et al. 2001, p. 40). Annex E of ISO 1999 (1990) indicates that the median threshold shift, even after four decades of very high intensity industrial noise exposure is moderate—not severe or profound- in degree, and the observed deterioration is gradual and nonlinear, reaching an asymptote in time. For example, Table E.4 (ISO 1990, p. 16) shows that the 0.5 fractile (i.e., median threshold value for the population) at 4000 Hz, after regular exposure to 100 dB ($L_{Aeq,8\,h}$) for 10 years is 31 dB; for 20 years, 36 dB; for 30 years, 39 dB; and for 40 years, 41 dB. This represents decreasing increments of 31, 5, 3 and finally, 2 dB per respective decade, in response to long and intense regular exposure. It is also noteworthy that the population data presented in ISO 1999 demonstrate that age-related threshold shift typically overlaps NITS later in life, as listed in Table B.1 of the standard (ISO 1990).

Nevertheless, although the extent of the risk may have been overstated by some commentators, recent evidence (including "daily life" SPL measures) indicates that a proportion of young people *are* exposed to noise doses sufficient to cause injury (Beach et al. 2013c). Beach et al. (2013c) recently estimated that ~15% may be affected. Although more conservative (lower) than some suggestions, this still represents a significant proportion of the population. The current authors agree with others (Smith et al. 2000; Schlauch & Carney 2012) that public education is of continuing importance. However, it is equally important that the leisure-noise risk is not overstated, at the potential cost of losing public credibility, and also diverting attention from the serious and ongoing problem of occupational noise. The additive effects of work, nonwork, and purely recreational noise sources must also be seriously considered (Williams 2009). Despite the large volume of data collected in this field, no specific damage-risk criteria for leisure-noise exposure are currently available (Portnuff et al. 2013).

Implications for Future Research

Where PTA is used, it is imperative that protocols ensuring the highest level of precision are put into place (Macrae 1998; Schlauch & Carney 2007). Better quantification of the multiple sources of experimental uncertainty (e.g., measurement error, selection biases, confounding variables) is vital in designing studies that produce both meaningful and economical outcomes (Phillips 2001). It also appears that the field would benefit greatly from the establishment of a consistent and scientifically justified approach to hearing loss criteria.

Previous commentators have suggested that paradigms other than conventional PTA should also be explored (SCENIHR 2008). Suprathreshold tests (e.g., speech-in-noise assessments) and objective techniques (e.g., auditory brainstem response, cortical auditory evoked response, and MEG testing) may extend the evidence base regarding subclinical changes to the auditory system. Ideally, longitudinal studies would be implemented, with baseline measures collected in the preteen years when noise exposure is minimal. However, the current authors recognize the logistical challenges and high cost of this type of research. Thus, cross-sectional studies of clearly at risk groups (e.g., frequent nightclub attendees) may be useful. Amassing clinical details (including measures of hearing disability) of leisure-noise exposed individuals, with no other risk factors for hearing loss, may also be informative. The establishment of clinical databases to collate relevant information across localities, or even countries, could be considered.

The use of amplification potentially provides an additional risk factor for increased threshold shift, particularly in high-noise leisure environments. The current authors noted the lack of data concerning leisure-noise exposure and effects for young hearing aid wearers (with early onset sensorineural hearing loss). This deficiency in knowledge is currently being addressed through an ongoing survey conducted by NAL. Lastly, to quantify the real individual and societal costs of leisure-noise exposure, more evidence regarding the actual hearing difficulties (i.e., disabling/handicapping effects) of leisure-noise–exposed individuals is greatly needed.

CONCLUSIONS

Some of the commentary in this field of research to date is arguably more speculative than evidence based. Information provided to public health authorities, educationalists, the media, and the community at large must be evidence based and scientifically defensible. Scientists should be prepared to challenge overstated or over-paternalistic, public information. The real cost versus benefit of future leisure-noise research should be carefully considered, and the freedom of individuals to make personal choices about their recreational pursuits, based on accurate scientific information, should be acknowledged in this process. At a global level, epidemiological and other health research directly consumes millions of dollars every year (Phillips 2001). It is therefore imperative that future investigators do everything possible to ensure that unambiguous and meaningful conclusions can be reached in future leisure-noise research.

DEFINITIONS

1. Loud sound encountered during everyday leisure activities is variously referred to as "leisure noise," "social noise" (Smith et al. 2000), and "sociacusis" (Ward 1976; MRC 1986; Yaremchuk et al. 1997). The term "leisure noise" is used in this review.
2. The terminology associated with "hearing loss" also varies in the literature and among authorities (e.g., standards organizations and professional bodies). Whatever the nomenclature used, the following concepts should be differentiated: (1) *Threshold shift* (or *threshold impairment*), that is, deviation or worsening of individual hearing threshold levels (HTLs) from a baseline or alternately; the HTL of an individual (or group) in relation to an accepted audiometric standard (WHO 1980); (2) *Noise-induced threshold shift* (*NITS*), that is, threshold shift attributable to noise exposure *alone*; and (3) *Hearing handicap* (or *hearing disability/hearing impairment*), that is, the individual disadvantage in everyday life imposed by threshold shift, particularly in terms of understanding conversational speech (ISO 1990, p. 3). "Hearing loss" generally refers to threshold shift in this review.

ACKNOWLEDGMENTS

The authors thank the extensive contribution of Joy Fischer (National Acoustic Laboratories Librarian) in sourcing and obtaining the material for this review.

Parts of this article were presented as an oral poster at the Audiology Australia XX National Conference on July 1–4, 2012 at Adelaide, Australia.

The authors declare no conflict of interest.

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Received July 26, 2013; accepted March 20, 2014.

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