PREVENTING HEARING INJURY IN THE MUSIC INDUSTRY

SIOBHAN MCGINNITY

ORCID 0000-0003-4598-2397

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Department of Audiology and Speech Pathology
The University of Melbourne
ABSTRACT

Sound levels in the live music industry have been demonstrated to reach levels capable of causing harm to the auditory system. The body of work presented here aimed to explore ways in which hearing injury can be prevented in the Australian music industry. To do so, multiple stakeholders were engaged, including venue owners, live-music sound engineers, audiologists and manufacturers of hearing protectors for musicians. Four discrete, mixed-methodology studies were conducted to address the topic.

Study 1 aimed to investigate the clinical provision of musicians’ hearing protectors (MHPs) by audiologists and manufacturers of MHPs in Australia.

Method. Audiologists and manufacturers were asked to complete one of two surveys, investigating the delivery of clinical care for musicians, and recommended processes relating to the manufacture of earplugs.

Results. Inconsistencies in the clinical procedures were noted in both the practice of audiological care for musicians, and the recommendations made by manufacturers of MHPs.

Study 2 aimed to investigate whether the use of, and satisfaction with, MHPs is influenced by the specific treatment delivered to musicians by audiologists.

Method. Musicians rated their satisfaction with the services as delivered across the four treatment conditions.

Results. No statistically significant differences across conditions were observed, however, certain aspects of care were perceived positively by musicians, such as the provision of a hearing test.
Study 3 aimed to assess the hearing of live music sound engineers and their risk of hearing injury.

**Method.** Participants completed a questionnaire on their hearing health as well as a hearing assessment.

**Results.** Ninety-six percent of sound engineers reported having experienced at least one symptom of hearing injury during or after a work shift in music. Use of hearing protection was low, however, individuals who frequently wore hearing protection had significantly better hearing, particularly in the extended high frequencies.

Study 4 aimed to investigate if the use of sound level management software can assist in reducing exposure levels in indoor live music venues.

**Method.** Use of a commercial sound level management system in six indoor live-music venues of Melbourne was trialled.

**Results.** Overall, there was no reduction in mean sound level (L$_{Aeq,T}$), however the number of nights on which extreme volume levels were recorded was reduced. Subjective questionnaires indicated that one-fifth of patrons would prefer lower sound levels than experienced.

Overall, the results indicate there is a significant risk of hearing injury to individuals working within and attending live music venues in Australia. Findings indicated that there is a need for greater hearing awareness across all stakeholders. Audiologists would benefit from the development of best-practice guidelines for the care of musicians’ ears, while more broadly, the inclusion of EHF hearing thresholds would benefit in early detection and monitoring of noise-induced hearing loss. Greater research focus and hearing
conservation training is needed for both LMSEs and staff in live-music venues, who would benefit from the implementation of strategies to manage venue sound levels in a way that takes into account the sound level preferences of patrons, while minimising the risk of hearing injury for all.
DECLARATION

I hereby certify that:

i) this thesis comprises only my original work towards the degree of Doctor of Philosophy, except where indicated in the preface;

ii) due acknowledgement has been made in the text to all other material used;

iii) the thesis is fewer than 100,000 words in length, exclusive of tables, maps, bibliographies and appendices.

April 2019

_______________________
Siobhan McGinnity
This thesis is comprised of my own, original work, and contains no material previously published or written by another person, except where due reference has been made in text. The undertaking of this research was inspired by my experience working as both musician and audiologist, and personal endeavour to help people hear music for life. The PhD candidate, Siobhan McGinnity, was responsible for the development, preparation and execution of the dissertation. Critical revision and interpretation of the data was supported by supervisors Professor Robert Cowan, Dr Elizabeth Beach and Dr Johannes Mulder, who assisted with the quality of all written publications. Additional support was obtained from Dr Caitlin Barr and Mr Dominic Power for the critical revision of the publication resulting in Chapter 4. Statistical support was kindly obtained by Sandy Errey of the Statistical Consulting Centre at the University of Melbourne where required.

The status for each of the results chapters is outlined below:


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This thesis was supported by so many individuals in my life to whom I am incredibly grateful.

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Tell me what you listen to,
and I’ll tell you who you are.

~ Tiffanie de Bartolo
CHAPTER 1 INTRODUCTION

INTRODUCTION

1.1 OVERVIEW

Music is a fundamental part of the human experience, playing an integral role in cultural enhancement for thousands of years. However, excessive exposure to loud music can risk injury of the auditory system (Sadhra et al., 2002; Derebery et al., 2012; Beach, Williams & Gilliver, 2013). The World Health Organisation (2015) estimates 1.1 billion young adults are at risk of hearing injury due to unsafe listening practices. These include attending live music concerts, where sound levels have been recorded as capable of causing harm (Bogoch, House & Kudla, 2005; Petrescu, 2008; Serra et al., 2014). Furthermore, prevalence of hearing injury is reportedly rising, with many authors suggesting recreational listening is, at least in part, responsible (Shargorodsky, et al., 2010a; Dawes et al., 2014; Moore et al., 2017; Rhee et al., 2019). The risk extends to individuals working within live music, inclusive of musicians, sound engineers or music venue staff (Patel, 2008; Jamieson, 2015). Here, however, hearing conservation strategies, are often poorly adopted at both individual and organisational levels, leaving many at risk of permanent, yet preventable damage (Guo & Gunn, 2005; Kelly et al., 2012). Furthermore, straight-forward solutions such as removal of the sound source or physical barriers, are often inappropriate in a live music context, where risk mitigation is far more complex (Zhao et al., 2010; Lindenbaum, 2017).

To address the concerns surrounding the risk of hearing injury in the music industry, solutions that are both appropriate and sustainable must be developed. Central to this is the distinction between noise and music, in that for “noise” the sound which
creates the risk of hearing injury is a by-product of the activity (e.g. shooting or machinery), whereas for music, the sound which creates the risk of hearing injury is the product of the activity. This creates the dilemma of how to mitigate the risk of hearing injury while maintaining the quality of the product, i.e. the musical quality and its audibility. Solutions, therefore, must meet the needs of all stakeholders involved, including patrons attending live music for enjoyment, staff working within venues, and musicians creating the sound. In this thesis, each group of the relevant stakeholders were included in four discrete studies, investigating solutions to hearing injury prevention.

To provide a basis for understanding the specific risks of different stakeholder groups in the music industry, it is relevant to briefly review the literature in terms of the physiology of hearing and pathophysiology of hearing injury, as well as current approaches to hearing conservation This chapter outlines the above, highlights areas in the literature that this thesis will address.
1.2 ANATOMY OF AUDITION

The auditory system is comprised of a peripheral and central component. At the periphery lies the human ear, divided into three succinct parts; the outer, middle and inner ear (see figure 1). The lateral portion of the outer ear is easily visible to the external eye, made up of the cartilaginous pinna and concha bowl. Combined, they form a funnel like structure, which not only directs sound into the external auditory meatus but provides a resonant boost with a peak between 4 and 6 kHz of up to 10 dB HL (Kollmeier, 2008). A secondary resonance is provided to the magnitude of 17 to 22 dB HL at roughly 2.7 kHz, as sound waves travel down through the external auditory meatus (da Silva et al., 2014). At the end of this meatus lies the tympanic membrane, a tri-layered membrane with incredible sensitivity to sound pressure displacement (Yuksel et al., 2009). Externally the membrane is covered by a sheet of squamous epithelial cells, seamlessly connecting with the wall of the external auditory meatus, while medially, it is covered by cuboidal mucosal epithelium, connecting with the space of the middle ear. A sheet of interlacing collagen fibres make-up the inner third layer, largely granting the membrane its flexibility and strength. The membranes sensitivity is such that motion narrower than the diameter of a hydrogen atom can be detected yet hold its form at maximal displacement of 400 daPa (Hüttenbrink, 1988; Zhang & Duan, 2009).

The third component of the auditory periphery is the inner ear. This contains not only the sense organ for hearing, but also for balance. Reflecting its importance, the labyrinth of the inner ear is encased deeply within the hardest bone of the body, the petrous bone (Nolte, 2009; Alper et al., 2017). The hearing organ is known as the cochlea and takes the shape of a snail-shell coil. It houses three discrete chambers within it; the scalae vestibuli, tympani and media. The outer two scalae, the vestibuli and tympani, are filled with thick perilymph fluid, similar in composition to the extracellular fluid of the
brain. Each rise to meet each other at the helicotrema, or apex, of the cochlea. The third chamber, scala media, is encased within them and instead contains a unique-to-the-ear, potassium rich fluid called endolymph (Wangermann, 2002). At the entrance to the scala vestibuli is the oval window of the middle ear. When pressed upon by the stapes, perilymph is displaced, which travels up in waves towards the helicotrema, then back down the scala vestibuli. At the end of this chamber a secondary window, the round window, sympathetically moves in reverse phase to that of the oval window, allowing fluid movement uninhibited within the cochlea (Kollmeier, 2008; Saladin, 2017).

Figure 1. Pictorial representation of the outer, middle and inner ear used with permission from the University of Melbourne.

Lining the floor between the scalae media and tympani, is a semi-resonant structure known as the basilar membrane (see figure 2). At its base, the membrane is stiff and narrow, ideal for responding to high frequency wavelengths. As it spirals towards the apex, its shape widens and becomes more flexible, making this area more responsive to
lower wavelengths (Liu, Gracewksi & Nam, 2017). In this way, any movement of the basilar membrane is frequency-dependent, responding to sounds from 20 Hz at the helicotrema to 20 000 Hz at the base (Kollmeier, 2008). Situated along the length of the basilar membrane runs one of the most important components for audition, the organ of Corti. This contains micro-cellular structures known as hair cells (Liu et al., 2016). These comprise roughly 3000 inner hair cells (IHC), running in a single row along the organ, and 12000 outer hair cells (OHC), clustered in rows of three along the external wall (Wright et al., 1987; Glueckert et al., 2005). These cells differ in their function, as reflected by the number of fibres innervating them, for instance, roughly 90-95% of auditory afferent fibres innervate a single IHC, with only 5-10% innervating the OHC (Spoendlin, 1972; Guinan, 2010). Transmission of auditory information, therefore, largely falls to the IHC, to the extent that audition in their absence becomes impossible via the cochlea (Ryan & Dallos, 1975; Dallos & Harris, 1978). Outer-hair cells, however, appear to function to improve sensitivity of the system, especially to inputs of lower-amplitude. Atop both types of hair cells, sit a rod-like filament, known as a stereocilia. For the OHC, however, these make direct contact with a roof-like structure known as the tectorial membrane. When displaced by waves of motion, the stereocilia sheer against the tectorial membrane, altering the cell membranes permeability (Liberman & Dodds, 1984; Wright, 1984). When triggered, the electromotility of each OHC causes it to further vibrate, which in turn increases the movement of the basilar membrane and corresponding IHC. In this way, the OHC act as a non-linear amplifier, improving the systems sensitivity to lower inputs (Ashmore, 2008; Maoile´idigh & Ju¨licher, 2010; Nankali, Sasmal & Grosh, 2015).

Roughly 30,000 auditory nerve fibres make up the auditory nerve, their cell bodies contained within the spiral ganglion of the cochlea (Guinan, 2010). Laterally, they
innervate the hair cells via synaptic ribbon junctions, requiring the neurotransmitter glutamate to function (Kujawa & Liberman, 2009). Medially from the ganglion, axonal

Figure 2. Pictorial representation of three chambers of the cochlea (left); the scalae vestibuli (superior), media (medial) and tympani (inferior), and the outer and inner hair cell rows (right). Used with permission from the University of Melbourne.
projections cluster to form the body of the cochlea nerve, eventually converging with those of the vestibular nerve. Together, they create the vestibulocochlear, or eighth cranial nerve. From here, auditory nerve impulses are transmitted up through the internal auditory meatus, to the cochlea nucleus of the brainstem (Nolte, 2008). Unlike other senses, much coding of the auditory information occurs within each step of the brainstem, aided by a tonotopically organised system. At the cochlea nucleus, the first of several contralateral projections are made, with bifurcations up the ipsi- and contralateral lateral lemniscus, before converging on the inferior colliculus. Beyond this, projections are made to the medial geniculate body, a centre which acts to further refine the auditory signal (Cope, Baguley & Griffiths; 2015; Saladin, 2017). Along the entirety of this pathway, spatial, temporal and frequency cues are coded, such that by the time information reaches the primary auditory cortex, much has been analysed. In this way, information received at each ear is provided to both sides of the brain, an aspect important for such auditory skills as sound localisation (Nolte, 2008).

1.3 NOISE-INDUCED HEARING LOSS

Disabling hearing loss is estimated to impact more than 466 million people worldwide, a figure set to increase to 900 million by 2050 (World Health Organisation, 2015). As many as 21% of these individuals are estimated to have acquired this loss through occupational exposure to noise, known as ‘noise-induced hearing loss’ (NIHL; Nelson et al., 2005). Most commonly, this is due to repeated and prolonged exposure to high sound levels yet, may also occur instantaneously following impulse sounds exceeding 130 dBA (Hamernik et al., 1984; Bielefeld, 2015; Wada et al., 2017). Noise-induced hearing loss is a global problem. In Europe, it is the most commonly reported
occupational hazard, while 22 million workers a year are exposed to hazardous sound levels in the USA alone (NIOSH, 2015; European Agency for Safety and Health at Work, 2005). While many associate NIHL with a steady-state, broadband noise source (e.g. engine or machinery noise), music too has the capability to cause injury. When presented for loud enough, and long enough, the same patterns of auditory degradation are visible in populations’ music exposed, as with those regularly exposed to noise (Størmer et al., 2015; Pouryaghoub, Mehrdad & Pourhosein, 2017; da Silva et al., 2017). One difference, however, is that this injury is not contained to work-related exposure, with music not only occupationally exposed, but to a larger extent, recreationally so.

1.3.1 Physiology of Noise-Induced Hearing Loss

The mechanisms underpinning the physiology of NIHL are still heavily debated, with research ongoing. However, there appear to be two major pathways through which injury can occur; mechanical and metabolic (Bielefeld, 2015). In the immediate period following noise exposure, mechanical damage of the cochlea ensues, from swelling of the hair cells to loss of cellular rigidity, hair cell stereocilia being particularly vulnerable (Liberman & Dodds, 1987; Ahmad, Bohne & Harding, 2003; Henderson et al., 2006). Histologically, stereocilia have been viewed as bent, tangled, fused, splayed etc. post traumatic noise exposure, which when significant enough, can lead to their detachment from the tectorial membrane (Nordmann, Bohne & Harding, 2000). When this occurs, the shearing mechanism of the tectorial mechanism against the hair cell stereocilia is disrupted, reducing OHC stimulation and preventing their ability to optimally function. (Lindgren & Axelsson, 1983; Nordmann et al., 2000). Depending on the degree of injury, this type of damage may recover, with function returning to normal over the course of a
few days to weeks, (Miller, Watson & Covelle, 1963; Hamernik & Henderson, 1974; Fredelius, 1988). During periods of reduced function, however, individuals may experience a temporary threshold shift, a transient deterioration in hearing acuity, measurable via pre- and post-exposure audiological testing. However, if the healing ability of the cochlea is exceeded, a permanent threshold shift will result with permanent loss or damage of the hair cells and/or their synaptic connections, though this requires additional processes to occur (Liberman & Dodds, 1984; Nordmann, et al., 2000).

Mechanically speaking, however, permanent damage can occur following an extreme amplitude surge of pressure level, causing the basilar membrane to move well beyond its capacity, leading to instantaneous harm (Hamernik et al., 1984; Henderson et al., 2007).

Initially it was thought that hair cell stereocilia were the primary target of noise-related injury, yet, in more recent years a second site has been reported. Studies have demonstrated noise-related loss of synaptic ribbon junctions underlying each IHC, connecting them with their primary afferents (Puel, 1995; Kujawa & Liberman, 2009; Cho et al., 2013). As explained in section 1.2, these synapses rely on glutamate to function, yet when in excess, either through poor re-uptake or overexpression, this neurotransmitter becomes excitotoxic (Pujol & Puel, 1999). Initially, noise-induced excitotoxicity causes post-synaptic swelling, which can lead to membrane rupture and dysfunction of the synaptic ribbon junctions. However, ongoing effects are caused by a disruption of cellular homeostasis, triggered by an influx of calcium to the IHC (Puel et al., 1996; Fridberger et al., 1998; Orrenius, Zhivotovsky & Nicotera, 2003). Once this occurs, a cascade of events follows, including, most notably, the release of reactive oxidative and nitrogen species (Dröge, 2002; Henderson et al., 2006). More commonly known as ‘free radicals’, these molecules disrupt intracellular processes, reacting with all cell components, from DNA to their cellular matrix (Bielefeld, 2015; Ewert et al., 2017).
CHAPTER 1 INTRODUCTION

Thought to be a by-product of an overexerted mitochondria, they linger in the cochlea post exposure, traversing from base to apex over the course of seven to ten days (Yamane et al., 1995; Yamashita et al., 2004; Kurabi et al., 2016). The ongoing effects of these processes can continue for months after exposure to noise, with evidence from animal studies suggesting necrosis and loss of auditory nerve fibres up to six months post-event exposure (Kujawa & Liberman, 2009).

1.3.2 Noise and the Audiogram

The key component of any hearing assessment is an audiogram, a graph outlining the lowest sound levels an individual can hear across a range of frequencies. The frequencies commonly tested are 250 to 8000 Hz. Less often, the extended high frequencies above 8000 Hz are included. Traditionally, NIHL has been characterised in the audiogram as a down-turned triangle, known as ‘the noise notch’, centred between 3000 to 6000 Hz (McBride & Williams, 2001; Hong, 2005; Meyer, 2007). This pattern has been reported to occur bilaterally, though asymmetries are sometimes noted, for example, in cases of exposure to rifle shooting where the breech is closer to one ear, or in violinists, who’s left ear is more exposed to the body of the instrument (Keim, 1969; Moon, 2007; Nageris et al., 2007; Schmidt et al., 2014). If the exposure to hazardous sound continues, this pattern worsens, reducing audibility of the high frequencies before spreading to also encompass the low frequencies. However, some research indicates that the extended high frequencies may be affected before, if not in a similar time period, to the development of the initial noise notch (Serra et al., 2005; Mehrparvar et al., 2014). Due to this, some researchers have suggested that extended high frequency testing could be an effective screening tool for NIHL (Singh, Saxena & Varshney 2009; Mehrparvar et
Regardless, if excessive sound exposure continues, hearing thresholds will continue to decrease and hearing difficulties will arise (Gomaa et al., 2014; Aazh & Moore, 2017; Bhatt, Bhattacharyya & Lin, 2017). For workers in the music industry, where hearing acuity is often central to their passion, profession and identity, the negative impacts of hearing loss can be magnified (Størmer, Sørlie & Stenklev, 2017).

1.4 MUSIC-INDUCED HEARING INJURY

If an individual is regularly exposed to loud music, they may suffer from NIHL. In this context, however, it is often referred to as music-induced hearing loss (MIHL). Prevalence rates of between 17 and 50% have been reported in both classical and pop/rock musicians (Kähäri et al., 2001; Kähäri et al., 2003; Emmerich, Rudel & Richter, 2008; Amorim et al., 2008; Jansen et al., 2009). Though some studies have not found evidence of MIHL in musicians, those that have span multiple genres, demonstrating the more determinant role factors such as intensity of the music played and distance of the sound source to the ear, play (Di Stadio, 2017). Furthermore, the hearing of those regularly exposed to music at high levels for their work, is also impacted. In a study by El Dib and colleagues (2008), for example, 50% of the 82 individuals working with sound systems presented with high-frequency hearing loss compared to just 10.5% of controls. Hearing loss in patrons due to recreational exposure is also reported, with live music concerts and nightclubs posing the greatest threat for overexposure (Bogoch et al., 2005; Petrescu, 2008). However, hearing loss is but one sign of injury to the auditory system when exposed to high levels of sound. In a 2003 report by Kähäri, reported that 74% of 139 rock/pop musicians experienced at least one symptom of hearing injury, including tinnitus, hyperacusis, diplacusis and distortion, all of which are explored below.
1.4.1 Tinnitus

Tinnitus is the experience of hearing a sound in the head or ears in the absence of any external source (Møller, 2010; Roberts et al., 2010). It is usually classified into two categories: objective, with the sound audible to a medical examiner; and subjective, unable to be heard by individuals other than the person experiencing it (Heller, 2003; Kaylie, 2019). Exposure to music and noise is associated with subjective tinnitus. Here peripheral injury (e.g., OHC damage post-noise exposure) leads to aberrant changes in the auditory pathway up to and including the central auditory cortex (Eggermont, 2014). These alterations can include increased spontaneous firing rate of fibres within the auditory system, altered neural connectivity, and morphological changes along the auditory pathway (Adjamjan et al., 2014; Rauschecker et al., 2015; McMahon, Ibrahim & Mathur, 2016). Even after severing the auditory nerve, which removes external input altogether, tinnitus may persist, demonstrating its central involvement (House & Brackmann, 1981). The psycho-social complications of tinnitus can be severe, leading to insomnia, anxiety, poor concentration, and in some cases, suicidal ideation (Lewis, Stephens & McKenna, 1994; Gopinath et al., 2010; Bhatt, Bhattacharyya & Lin, 2017; Crönlein, 2017).

Prevalence estimates suggest that 10 to 25% of the global population live with subjective tinnitus, and 3% experience permanent chronic tinnitus (Shargorodsky, Curhan & Farwell, 2010b; Fujii et al., 2011; Nondahl et al., 2011; Yang et al., 2018). However, this figure appears to be increasing, especially in adolescents and young adults (Gilles et al., 2013; Dawes et al., 2014; Moore et al., 2017). Several authors suggest that recreational exposure to excessive sound levels from music concerts, nightclubs and personal music players might be, in part, responsible for this increase (Bogoch, 2005; Szibor et al., 2018). For example, when testing the hearing of 29 patrons before and after a pop/rock concert,
Derebery (2012) reported that 25% experienced tinnitus post-concert. In a survey of over 9000 young adults, Chung et al. (2005) found 43% had experienced tinnitus after attending a nightclub, and 61% after a live-music concert. The experience of tinnitus also appears to be common in employees of entertainment venues, with incidence increasing with duration of employment (Gunderson, Moline & Catalano, 1997; Jamieson, 2015). Rates of tinnitus have also been reported to be higher in musicians as compared to the general population (Størmer et al., 2015; Schmidt, Paarup & Baelum, 2019). The additional consequence for musicians, however, is having to practise their trade which relies on accurate feedback of sound, in the presence of an additional, intrusive “noise” within the auditory system.

1.4.2 Hyperacusis

The human auditory system can perceive sounds over an incredibly wide range of intensities, and for most people, sounds up to 120 dB HL can be tolerated before pain is elicited. In the case of hyperacusis, however, this threshold can be much lower (Hood & Poole, 1966). Hyperacusis, is the sensory experience of reduced sound tolerance, such that sounds perceived as tolerable by others, are intolerable to the person affected (Baguley, 2003). While definitions vary, most agree intolerance below 90 dB HL is abnormal, with clinical severity increasing as this is lowered (Sherlock & Formby, 2005; Aazh, McFerran & Moore, 2018; Aazh & Moore, 2018). It is estimated that roughly 8-15% of the population experience a degree of hyperacusis, though the underlying cause remains unknown (Andersson et al., 2002; Gilles et al., 2012). The overarching theory is that with reduced peripheral input, be it through auditory depravation or hearing loss, central gain of the auditory system is increased to the point of hypervigilance (Formby, Sherlock & Gold, 2003; Munro & Blount, 2009; Auerbach, Rodrigues & Salvi, 2014;
Brotherton et al., 2015; Eggermont & Roberts, 2015). Studies in the experimental animal have suggested that exposure to excessive sound levels may be a risk factor for developing hyperacusis (Alkharabsheh et al., 2017). These findings are consistent with reports in the literature of increased prevalence of hyperacusis in individuals with high levels of work-related noise exposure (Axelsson and Hamernik, 1987). The latter being relevant to this thesis, where complaints of sound intolerance in musicians, assumedly high exposed to sound, are reported between 6.3 and 45% (Kääriä et al., 2003; Jansen et al., 2009; Toppila, Koskinen & Pyykkö, 2011; Putter-Katz, Halevi-Katz & Yaakobi, 2015; Pawlacyzk-Luszczyńska et al., 2017).

Living with hyperacusis can be a debilitating experience, with many individuals relying on hearing protection or avoidance behaviours to cope with their aural environment (Blaesing & Kroener-Herwig, 2012). Furthermore, this discomfort can manifest in physical symptoms, such as aural pain, discomfort and vertigo (Aazh & Moore, 2018; Baguley & Hoare, 2018). For workers and attendees at live music venues, it can be particularly restrictive, limiting their capacity to safely and comfortably engage with music. This problem was exemplified recently in the case of a violist who received compensation for hearing injury incurred during a rehearsal of Wagner’s Die Walkure. In this case, sound levels exceeded 130 dB, and the violist experienced instantaneous pain, tinnitus and vertigo (Coleman, 2018). Subsequently, the musician’s tolerance for sound was impaired to the extent that playing, rehearsing or listening to music became virtually impossible. In his own words, the experience of listening was now akin to ‘walking barefoot on glass’ (Coleman, 2018).
1.4.3 Diplacusis, Distortion & Dullness

From the Greek words ‘diplos’ (double) and ‘akousis’ (hearing), diplacusis describes an anomaly where a singular sound is heard as two separate pitches (Culpepper, 1961; Ichimiya & Ichimiya, 2019). More often this occurs binaurally, with the same tone experienced as two different pitches between the ears, yet it can also occur monaurally, with the same tone heard as two discrete pitches in the same ear (Formby & Gjerdingen, 1981; Knight, 2004). The breadth of the pitch discrepancy between the true, and introduced pitch, can be as wide as a quarter octave. This can be heard either lower or higher than the true pitch, and cause great difficulty surrounding pitch perception and performance for those affected (Culpepper, 1961; Albers & Wilson, 1968). While it can occur in individuals with normal hearing, it is more often seen in association with sensorineural hearing loss, in particular asymmetrical losses (Colin et al., 2016). Though not as common as other forms of hearing injury, prevalence between 4 and 7% of musicians is reported, in classical and rock/pop musicians alike (Kähäri, Zachau & Eklöf 2004; Jansen, 2009; Laitinen & Poulsen, 2008).

One symptom of the cochlear damage induced by excessive sound exposure, can be identified in sequential audiograms as a change or shift in hearing thresholds. Temporary threshold shifts following music exposure have been reported in musicians, patrons and staff of live music venues. For example, in an audiometric comparison pre- and post a two-hour amateur orchestral rehearsal, deterioration of up to 20 dB was observed by Penzkofer and colleagues (2015). In this study, the musicians with the greatest temporary shift were also those with the greatest sound exposure; a trumpeter and drummer exposed to more than 97 dBA during rehearsal. Here, the greatest reduction in hearing was of the more vulnerable high frequencies, between 6 and 8 kHz, however reduction in other frequencies was noted. Similarly, temporary threshold shifts of up to
15 dB have been recorded in patrons after live music attendance, and up to 21 dB in employees of entertainment venues (Sadhra et al., 2002; Derebery et al., 2012). Often, these shifts are reported alongside the subjective experience of hearing dullness, or temporarily worsened hearing. For example, authors Tin and Lim (2000) measured the hearing of 48 patrons attending two music discotheques. After four hours of exposure to either 101 dBA or 108 dBA, respective of the discotheque chosen, temporary shifts of 15 dB or greater were observed in more than 70%. Furthermore, 76 and 82% of patrons, respectively, reported their hearing to be noticeably worse immediately after. Unfortunately, the mechanisms as to why some individuals experience a temporary change in hearing and others don’t, after the same degree of sound exposure, is still widely unknown (Davis, Kozel & Erway, 2003).

The last form of hearing injury covered here is that of distortion. Akin to the sound of an overexerted speaker, hearing distortion is typically the experience of sound alterations at peak volumes. Laitinen and Poulsen (2008) more closely define the it as, ‘when sound reaches a certain level, it is perceived as being impure, cracked, distorted’ (p. 164). At its extreme, distortion can be caused by cochlea ‘dead regions’ - sections of the organ of Corti in which functioning health IHC are found to be absent and/or low in number. In these cases, subjects report altered pitched percepts and frequency resolution (Moore, 1996; Moore et al., 2000). However, this usually occurs in the presence of hearing loss greater than 80 dB HL and would not explain most reported cases in musicians. As for prevalence, one study investigating hearing injury in rock and pop musicians reported distortion in 24%, with men more often affected than women (Kähäri et al., 2003). Similarly, 24% of 245 orchestral musicians reported hearing distortion in a study by Jansen and colleagues (2009), though it has been reported somewhat to a lesser degree by others (Laitinen & Poulsen, 2008).
1.5 HEARING CONSERVATION IN MUSIC

In most jurisdictions, legislation exists to control the risk of sound exposure and to safeguard the hearing of employees. In Australia, these laws mandate that sound level exposure must not exceed the exposure standard of 85 dB $L_{Aeq}$ for an eight-hour work day (Standards Australia, 2005). A 3-dB exchange is applied such that when the sound pressure level doubles (increases by 3 dB), exposure time must be halved. Accordingly, 88 dB $L_{Aeq}$ is considered acceptable for four hours, 91 dB $L_{Aeq}$ for two hours, and so on (Standards Australia, 2005). In situations in which these levels are exceeded, measures must be taken to reduce and prevent the risk of hearing injury, such as the use of sound barriers or hearing protectors (Worksafe Victoria, 2018). However, translating these regulations from the workplaces they were designed for (e.g., factories, plants and mines) is problematic for the music industry. Music is the primary reason that people are exposed to the risk of MIHI, i.e. they put themselves at risk because they want to enjoy music and the social environments in which it is presented. In many music venues sound levels regularly exceed the criterion of 85 dB $L_{Aeq}$, with exposure as up to 110 dB $L_{Aeq}$ recorded by several authors (Cabot, Genter & Lucke, 1979; Yassi et al., 1993; Moshi, 2002; Kelly, Boyd & Henehan, 2015; McGinnity et al., 2018). Under these circumstances, it is highly likely that exposure may lead to hearing injury, yet many of the traditional forms of hearing conservation, such as sound restrictions, sound barriers and hearing protection, are either not applied, or are systematically problematic for music venues (Guo & Gunn, 2005; Barlow & Castilla-Sanchez, 2012).

In a traditional workplace setting, it is typically only employees who are exposed to high sound levels and in need of hearing protection. In the music industry, however, the hearing of musicians, sound engineers, patrons and staff all need to be taken into consideration. Addressing the risk of hearing injury in the music industry, therefore, is a
much more complex issue. To better accommodate the needs of the music industry, guidelines have been formulated by various bodies to guide practice. Though they exist, a Western Australian study has indicated that the implementation of hearing conservation strategies in music venues remains to be low. Of 16 venues investigated, only 23% had conducted a noise assessment, 18% had implemented a noise policy (including training of staff), and just over half provided hearing protectors to employees. Furthermore, the sound exposure of staff was documented to have steadily increased over a five-year period (MacMillan & Gunn, 2000; Guo & Gunn, 2005). It would appear, therefore, that procedures surrounding hearing conservation in music venues are much less adopted than in industries outside of music.

To address the need for hearing injury prevention in live music venues, while managing the competing demands of producing music and entertaining patrons, holistic, venue-driven solutions are required, empathic to the needs of all stakeholders (Horrell, 2013). One solution that has arisen from within the industry is the use of sound level management software (Navne, 2015; Mulder, 2016). Such systems allow venues to create sound level targets, commonly $L_{\text{Aeq,15min}}$, that sound engineers can aim to keep beneath. They also provide real time monitoring of the sound levels within the venue, keeping sound engineers and stakeholders continually informed. Although these sound level management systems were initially developed with a focus on environmental noise reduction and are often used for large-scale open-air concerts, they may also offer a solution to indoor live music venues. However, to date all research into the effectiveness of these systems has focussed on outdoor concerts and festivals (Kok, 2015; Tronstad & Gelderblom, 2016).
1.5.1 Hearing Protection

One common method of hearing conservation in live music venues is the use of hearing protectors. While there are many ways in which hearing protectors can be classified, in this thesis the taxonomic distinction will be between active and passive earplugs. Active hearing protectors are those which include an electronic component that ‘actively’ compresses sound levels. Typically, these work such that loud levels are attenuated, while inputs are either maintained or provided minor amplification (Killion, DeVilbiss & Stewart, 1988). Passive protectors on the other hand, are without an electronic component and act as a physical block to sounds entering the ear. The common foam earplug (i.e. PVC or PU), earmuffs or filtered, silicon earplugs are all examples of passive hearing protectors. While each type offers demonstrable benefit to the listener, uptake by staff, patrons and musicians has been consistently reported as low. In a survey of more than 9000 young adults circulated by American entertainment network, MTV, only 14% had used protectors at a concert, although as many as 61% reported that they had experienced tinnitus afterwards. Furthermore, more than half said they would negatively judge a peer for using protectors, highlighting the stigma associated with protective behaviours (Chung et al., 2005). This is a finding that has also been documented more broadly, and in an Australian context, with patrons rarely using hearing protectors (Goggin et al., 2008; Beach, Williams & Gilliver, 2010; Carter, 2011; Beach, Williams & Gilliver, 2012). Unfortunately, low use of hearing protection has also been documented in staff members and sound technicians of entertainment venues, as well in musicians, where risk is likely to be higher due to the frequency of sound exposure, (Gunderson et al., 1997; Sadhra et al., 2002; El Dib et al., 2008; Jamieson et al., 2015).

To perform to the best of their ability, musicians need to hear their instrument, and others’ instruments with clarity. As traditional foam earplugs attenuate sound across
the frequency spectrum to different degrees, their effect is to change the sound as heard by the user, making it more difficult to perform. To address this, musicians’ hearing protectors (MHP) were designed in the 1980s, to allow for relatively flat reduction of sound across the frequency spectrum (Killion, Devilbiss & Stewart, 1988). Composed of a custom-moulded silicon plug, MHPs contain a hollow sound bore through the middle, with an interchangeable diaphragm, known as a filter, on the external side. Through the balance of acoustic mass of the sound bore, and compliance of the filter, the plugs are designed to help recover loss of the natural resonance of the ear, while protecting against incoming sound. Yet although studies have documented the benefits to musicians of wearing these devices, such as reduced tinnitus and listening fatigue, issues still arise and uptake amongst musicians remains relatively low (Huttunen et al., 2011; Halevi-Katz et al., 2015; Beach & O’Brien, 2017).

To make a custom MHP an ear impression must be made. Typically administered by an audiologist, it involves the injection of material into the ear that sets over four to six minutes. This material is then sent to a manufacturer to create the hearing protector from this mould. However, there are many variables involved in the creation, from impression technique to type of impression material, and each of these may alter the fit, comfort and protection of the final product. Furthermore, when ordered, options such as canal length and filter strength may change how the earplug feels and sounds to the user. To date, no study has investigated how systematic alteration of earplug options or mode of care delivery by an audiologist may influence usage and satisfaction outcomes. Considering the low use of hearing protectors and risk of hearing injury, it is paramount that all aspects of use and creation of MHPs are explored to encourage uptake and ensure career longevity for musicians.
1.6 OVERALL AIM

This thesis aimed to investigate practical ways in which the risk of hearing injury in the music industry could be reduced. Four studies were designed that engaged multiple stakeholders within the music industry, and the audiologists who provide them services, in an attempt to identify targeted solutions. The aims of the four studies were:

Study 1: to investigate the clinical provision of musicians’ hearing protectors by audiologists and manufacturers of MHPs in Australia.

Study 2: to investigate whether the use of, and satisfaction with, MHPs is influenced by the specific treatment delivered to musicians by audiologists.

Study 3: to assess the hearing of live music sound engineers and their risk of hearing injury.

Study 4: to investigate if the use of sound level management software can assist in reducing exposure levels in indoor live music venues.

1.7 OUTLINE

In the following chapter, the methodological approach and procedures for each study will be outlined. Chapters 3 to 6 have either been published or submitted for publication in peer-reviewed journals. The final chapter presents a summary of the findings from each study, along with the relevant conclusions and recommendations for industry.
In Chapters 3 and 4, an exploration of how the audiology industry may influence hearing injury prevention in musicians is presented. Chapter 3 (Study 1) explored the standards of clinical practice for musicians using the results from questionnaires completed by audiologists and manufacturers of MHPs. In Chapter 4 (Study 2), four models of MHP delivery and care provision were explored to investigate whether audiologists’ service delivery can influence musicians’ use of, and satisfaction with, hearing protectors. In Chapter 5, (Study 3) the hearing health of live music sound engineers was assessed, alongside exploration into their use of hearing protection, listening behaviours, and risk of hearing injury. Finally, in Chapter 6 (Study 5), the use of sound level management software, 10EaZy, was trialled in six indoor live music venues, with the aim of assessing its effectiveness in reducing overall sound level exposure of patrons and staff.
REFERENCES


Chapter 1: Introduction


Mathematics is on the artistic side a creation of new rhythms,
orders, designs, harmonies,
and on the knowledge side,
is a systematic study of various rhythms,
orders, designs and harmonies.

~ William L. Schaaff
2.1 GLOBAL RATIONALE

This chapter introduces the general design and rationale behind the construction of this thesis. As elucidated in Chapter 1, several gaps in the literature exist within the topic of hearing in the music industry, a relatively green area of research. As such, it was the intent of the author to approach the topic with a global approach of exploration. In line with this, four discrete studies were conducted that traversed two key industries; audiology and the live-music industry. Broadly speaking, Study 1 and 2 explored elements relating to the improvement of hearing-service provision, while Studies 3 and 4, explored the problems and associated solutions within the live-music scene. For all, a confirmatory approach was adopted, with discrete aims and hypotheses created. Specifically, these aims were:

Study 1: to investigate the clinical provision of musicians’ hearing protectors by audiologists and manufacturers of MHPs in Australia.

Study 2: to investigate whether the use of, and satisfaction with, MHPs is influenced by the specific treatment delivered to musicians by audiologists.

Study 3: to assess the hearing of live music sound engineers and their risk of hearing injury.
Study 4: to investigate if the use of sound level management software can assist in reducing exposure levels in indoor live music venues.

2.2 STRATEGY OF INQUIRY

Appreciative inquiry is a research strategy with a foundation in organisational psychology, that approaches the hypothesis with a solution-based focus (Cooperrider, Whitney & Stavros, 2008; Teevale & Kaholokula, 2018). Traditional problem-based methods of inquiry focus on cause identification, while appreciative inquiry is action-based, aimed at achieving ‘real-world’ change (Potvin, Petticrew & Cohen, 2014). As a paradigm, it assumes that many of the answers to problems can be found within the target population, and as such, focuses on industry and/or community engagement (Whitney & Trosten-Bloom, 2010). As this thesis aims to explore hearing injury prevention in the music industry, engagement of both the hearing and music sector was necessary. With a desire to foster engagement of both communities and the inclusion of them in creating change, adoption of elements of appreciative inquiry, therefore, was both rational and beneficial to each studies outcome.

Two components of appreciative inquiry incorporated into the design of this thesis were wholeness and engagement (Whitney & Trosten-Bloom, 2010). Wholeness requires the inclusion of all stake-holders in the process towards a creative solution, which can be best demonstrated by Study 4. In this study, stakeholders from the live-music community were crucial to its success, requiring the active participation of venue owners, managers and staff at multiple points in the study. Furthermore, engagement was fostered through a collaborative approach to the experimental design, allowing each venue to select a
sound level target they wished their venue to achieve. In this way, each venue was able to act with self-determination, throughout participation.

2.3 RESEARCH DESIGN

Mixed methods research involves the collection, analysis and interpretation of data from both quantitative and qualitative sources (Leech & Onwuegbuzie, 2008). Stretched over one or many studies, it combines both methods in the pursuit of addressing a singular phenomenon (Creswell & Plano Clark, 2007). At its core, mixed methodology assumes the research question can best be answered through the combined strengths of both data sources (Andrew & Halcomb, 2006). As such, it is often used to address more complex social and scientific problems, allowing for concurrent exploratory and confirmatory design.

For this thesis, a mixed methods research design was adopted for all four studies, with qualitative and quantitative data concurrently collected. In some instances, concurrent nesting was used, whereby qualitative data played a supporting role to the dominant quantitative (see table 1). For example, in Study 3, live music sound engineers underwent a hearing test, where objective, quantitative information was obtained on each participants’ hearing. This was later assessed in the context of subjective commentary made by participants, such that the impact of objective data could be more holistically understood. The remaining studies used a strategy of concurrent triangulation. Here quantitative and qualitative data held equal weighting, and integration occurred at analysis or interpretation (Creswell, 2003).
2.3.1 Rationale for mixed methods design

While providing many benefits, mixed methods design can be problematic and resource intensive. Requiring the development of both quantitative and qualitative elements, it can involve more time in conception, design, data collection and analysis than other methods alone. However, as it allows for greater depth and understanding of a topic, it was considered necessary for it to be used in this research project. The state of hearing health in the music industry is a complex topic, involving stakeholders from government bodies to patrons, each with their internal biases, experiences and beliefs. To appropriately explore each research question, mixed methodology that allowed for both exploration and confirmation of the hypothesis was required.

A limitation of mixed methodology comes during the integration of data, where comparison of the divergent data types is made. The qualitative elements of this thesis were obtained via survey research. To coherently link the results of questionnaires with data quantitatively sourced, thematic analysis was used. Thematic analysis is the process of categorising qualitative responses into sensical topics or themes (Boyatzis, 1998; Guest, 2012). These can be statistically reported, or where required, ranked in order of frequency of occurrence. An example of its use can be seen in Study 2, where musicians were asked what instrument(s) they played. To better understand the profile of participants, the instruments reported were segregated into categories and ranked, allowing interpretation on two levels, one in that most musicians were multi-instrumentalists, and secondly, that the most commonly played instrument was guitar. Through use of thematic analysis, the qualitative sources of data for this thesis could clearly and concisely be integrated with the quantitative elements of each study.
The quantitative data collected in this study were from closed questionnaire items, objective clinical assessments and sound level measurements. The clinical assessments selected were ones routinely performed in standard audiology, with robust validity and reliability. These included, but were not limited to, pure-tone audiometry – a measure of one’s hearing acuity, speech discrimination testing – a measure of speech intelligibility in quiet, and uncomfortable loudness levels – measuring an individual’s tolerance for volume at varying pitches. A second objective source came from sound level measurements, recorded either via calibrated dosimeters (CEL dBadge), or use of 10EaZY. Use of these measures provided objective data complimented by subjective responses to open-ended questionnaire items.

2.4 SURVEY RESEARCH

Across all four studies, survey research was incorporated into the design. Survey research can be defined as the collection of data from a sample of individuals, through their responses to a list of questions (Check & Schutt, 2012). The questions used can be either closed-ended, with a designated response (i.e. “yes” or “no) or open-ended, allowing the participant to answer in a free-form manner and elaborate on their ideas (Singleton & Straits, 2009). A mixed methods strategy was used for each, incorporating both open and closed-items, allowing for both precision and participant elaboration.

2.4.1 Rigor of survey research

Survey research is a cost-effective, flexible method of capturing a broad range of ideas from a sample (Jones, Baxter & Khanduja 2013). However, as outlined by Ponto
(2015), there are four main sources of error to be considered that can reduce the reliability of a survey study: sampling, coverage, nonresponse and measurement error. To lessen the error in the surveys used here, strategies were implemented. Sampling error, where the individuals tested do not reflect the population, was assuaged by having a clearly defined target population, and parameters for participant inclusion/exclusion (Check & Schutt, 2012). Participants were selected from non-random samples that reflected the population and recruited using either convenience or snow-ball methods (Kelley et al., 2003). The latter was particularly pertinent when sourcing musicians or sound engineers, who were often able to recommend other individuals in the community that had not been reached through advertising.

Coverage error relates to the chance that the sample recruited does not reflect the target population (Singleton & Straits, 2009). This was addressed through the sampling technique and mode of recruitment for each study. Strict inclusion and exclusion parameters existed for each, with recruitment occurring through targeted networks directly engaged or related to the desired population. For example, where live-music sound engineers were required, advertisement were posted online, in sound-engineer forums and through related music peak-body networks. Each questionnaire was also delivered using an online platform, SurveyGizmo (Boulder, CO). In doing so, individuals were able to engage with the questionnaires in a personalised manner, with flexibility in choice of location and time. The latter assisted in reducing nonresponse error. Nonresponse error refers to the potential risk for a lack of, or low return in responses by invited individuals (Dillman, Smyth & Christian, 2014). By delivering the questionnaires online, accessibility was high and the administration load (i.e. returning of completed surveys via post) considerably reduced.
2.5 INDIVIDUAL STUDY DESIGN

The following section outlines the specific design, strategy, timeframe and procedure for each study, as shown in table 1. As discussed, a mixed methods design was used for all, with the qualitative components drawn from the open-ended items in each questionnaire. Study 1 was comprised entirely of two surveys, completed once by participants to provide a ‘snap-shot’ of responses. As both qualitative and quantitative elements were weighted equally in importance, concurrent triangulation was used. This involved the integration of data at the point of interpretation, a procedure also adopted by Study 2.

Table 1. Methodological design and process for each study

<table>
<thead>
<tr>
<th>Study</th>
<th>Design</th>
<th>Strategy</th>
<th>Timeframe</th>
<th>Procedure</th>
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<tbody>
<tr>
<td>1</td>
<td>Mixed method</td>
<td>Survey</td>
<td>Cross-sectional</td>
<td>Concurrent triangulation</td>
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<td>2</td>
<td>Mixed method</td>
<td>Experiment &amp; Survey</td>
<td>Cross-sectional</td>
<td>Concurrent triangulation</td>
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<tr>
<td>3</td>
<td>Mixed method</td>
<td>Experiment &amp; Survey</td>
<td>Cross-sectional</td>
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<tr>
<td>4</td>
<td>Mixed method</td>
<td>Experiment &amp; Survey</td>
<td>Longitudinal &amp; cross-sectional</td>
<td>Concurrent nested</td>
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Studies 3 and 4 differed from the first two in that the qualitative components of the study were nested within the dominant quantitative data. For example, over 22,000 minutes of sound recordings were analysed in Study 4, complemented by a small number of open-ended questionnaire items. As such, both Studies 3 and 4 adopted the procedure of concurrent nesting, with integration of data occurring at analysis and interpretation. Similarly, they also both made use of experimental and survey design elements, as did Study 2, to ensure the research question was best addressed. Finally, Study 4 differed from all in allowing for longitudinal collection of data. Sound levels were repeatedly
measured from the same location in each venue over a minimum of eight weeks in each venue, and results compared over time, across study conditions.

2.6 DATA COLLECTION & ANALYSIS

Data collection was obtained from questionnaires and clinical assessments undertaken by the research team. All data for clinical observations were recorded manually, before being entered electronically for analysis. Care was taken with data entry to ensure reliability of the data. Questionnaire responses were entered directly by participants online using online survey platform, SurveyGizmo (Boulder, CO). Physical data were stored at the University of Melbourne, while electronic data were stored in locked files on a password secured computer. All analyses were performed on version 25 of Statistical Packages for the Social Sciences software (SPSS Inc., Chicago, IL, United States). These included such types as descriptive statistics, ANOVA, Chi-square and Fishers Exact tests.

2.7 ETHICS

Ethical oversight of the four studies was provided by two governing bodies who approved the studies. Studies one and two, relating to the delivery of audiological services to musicians, were overseen by the School of Health Sciences Human Research Ethics Advisory Group of the University of Melbourne (Project Number 1646388). Study 3 and 4, relating to the hearing health of live-music participants, were overseen by the Human Research and Ethics Committee of the Royal Victoria Eye and Ear Hospital (Project Number 15/1225H).
Participants were provided plain-language statements and documentation outlining their rights and privacy. Informed consent was obtained prior to participation from all, and in the instance of a live-music venues involvement, consent was signed on the venue’s behalf by a venue-appointed delegate, such as the owner or manager. The conduct of all studies was consistent with the National Statement on Ethical Conduct in Human Research (NHMRC 2018; Australian Government, 2003).

2.8 VALIDITY

2.8.1 Internal validity

The concept of internal vs external validity was first introduced by Donald Campbell in 1957. Internal validity is the extent to which a study is truthful to what it reports to measure, while external validity explores the generalisability of the model (Slack & Draugalis, 2001). Internal validity is based upon two assumptions, firstly, that the study is repeatable, and secondly, that similar conclusions would be met if the same procedure was conducted by another researcher (Andrade, 2018). With greater internal validity, more confidence can be held in the reported cause and effect of each study, avoiding confounding (Patino & Ferreira, 2018). It was necessary to optimise, therefore, the probability of achieving a high level of internal validity from the outset.

The eight factors known to affect internal validity are history, maturation, testing, instrumentation, regression, selection, experimental mortality, and finally, the interaction of these factors (Andrade, 2018). Certain factors were nullified in this thesis due to its design. For example, the chance of maturation, the extent to which changes in the dependent variable are due to natural development, was low due to the short time-horizon each study existed within. However, three forms of threat to internal validity were
applicable; history, design contamination and experimental mortality. Experimental mortality explains the likelihood of participant withdrawal, relevant to Study 2 (Slack & Daugalis, 2001). In this study, two musicians withdrew, citing personal, financial and health reasons. Considering the study took place over a minimum of two consecutive months, the chance of participant withdrawal was high, a similar time-frame as was used for Study 4. Here, however, no participants (live-music venue), withdrew. It was observed that strong participant engagement and communication with the research team encouraged the longevity of participation in this study, where the withdrawal of even one live-music venue may have greatly affected the results.

Design contamination was also possible in Study 2. This refers to the ability of blinded participants to discover the condition in which they have been allocated, cross-contaminating results (Andrade, 2018). To reduce this risk, musicians were randomly allocated to one of four conditions, and kept blinded until after the final point of data collection. Several musicians, however, reported knowing other participants, and communication across conditions may have occurred outside the control of the research team. Finally, the threat of history contamination was relevant in Study 4. This threat refers to the occurrence of an event during data collection that influences the dependent outcome (Sørlie & Ogden, 2014). Due to the extent of variables each live-music venue contained (i.e. room layout or quality of equipment) that were beyond the control of the research team, it is possible the internal validity of this study was impeded, something taken into consideration when analysing results both within and between each venue.
2.8.2 Eternal validity

External validity is the extent to which the findings of an investigation can be generalised to the population the study sample represents (Steckler & McLeroy, 2008). It can be further segregated into population validity, relating to the ability of the study to create inferences on persons outside the study sample, and model validity, the way in which the experimental situation is translatable to the real-world setting (Khorsan & Crawford, 2014). Of the four studies described here, there was one study that presented difficulty in achieving robust model validity, Study 4 - investigating methods of sound-level management in live-music venues. By choosing to conduct this study within real live-music venues over a lab environment, the transferability of the study was strong. However, in doing so, variables were inherently introduced, outside the researcher’s control. Such variables included the physical structure of the room, the quality of sound equipment, the reverberation time and even the band performing at each given time. To counter-balance the influence of these, several measures were taken to bolster model validity, including the installation of the sound equipment in designated, fixed-locations, or the use of venues that closely represented the median capacity as reported by the Australian Live Music Office (2014). In this respect, while the internal validity may stand for each venue, inference of the findings to a broader musical context must be done with care.

The population validity of each study varied, restricted at times by sample recruitment and size. In study 1, for example, both high and low population validity existed. There are five known manufacturers of musicians’ hearing protectors to the researcher in Australia, and four agreed to participate in the study. In this way, the translation of the results pertaining to their survey can be assumed to be high. However, the sample size of audiologists participating in this study, was comparatively low
compared to the audiology workforce in Australia. Furthermore, the recruitment was skewed by responses of a highly musical audience, with audiologists having personal music history or a keen interest in the topic, participating. In this way, the results presented may present a biased representation of the population, and again, generalising the results to the broader audiology community should be done with caution.

2.9 SUMMARY

In this chapter the rationale, design and strategy of each study has been presented. Globally, the research took on an explorative approach with a solution-based focus. In this way, each study was constructed to lead towards tangible, real-world solutions and the engagement of industry. With consistency in their use of a mixed methodology, survey research and concurrent analysis, each study explores a differing facet of the guiding topic, hearing in the music industry. The following chapters present each study in detail and contain information on the specific methodological processes, reliability and limitations of each study.
REFERENCES


Musicians don’t retire,

they stop when there’s no more music in them.

~ Louis Armstrong
CHAPTER 3

PREVENTING HEARING INJURY IN MUSICIANS: INSIGHTS FROM AUDIOLOGISTS AND MANUFACTURERS REVEAL NEED FOR EVIDENCE-BASED GUIDELINES

The following peer-reviewed publication is incorporated in its entirety in this chapter, inserted as published, with the exception of formatting changes to headings, tables, figures and references to maintain consistency throughout the thesis:

Published paper


**Aim:** to investigate the clinical provision of musicians’ hearing protectors by audiologists and manufacturers of MHPs in Australia.
3.1 ABSTRACT

Objective: This study aimed to investigate the standard of care delivered by audiologists and manufacturers of hearing protectors to musicians in Australia. Design: Audiologists with experience treating musicians were invited to complete a survey about their service delivery. A second survey was administered to manufacturers of musicians’ hearing protectors (MHP). Study sample: Four manufacturers of MHP and 31 audiologists completed the surveys. Post-hoc analyses were performed comparing the responses of audiologists with more versus less clinical experience; and those with and without musical training. Results: There was considerable variation in the way that audiological care was provided to musicians. Only one-third of audiologists performed pure-tone audiometry prior to MHP fitting, and there was little consistency across the sample in relation to their make and order. There was also significant variation in the manufacturers’ approach to MHP, each of whom provided different recommendations regarding preferred impression techniques and material viscosity. Conclusions: The results of this study reveal lack of consistency across the hearing healthcare sector with respect to care of musicians’ hearing, with potential to impact upon the satisfaction with, and usage of, MHP. There is need for evidence-based, best practice guidelines and training to support clinicians in providing optimal care.
3.2 INTRODUCTION

Hearing loss is the second most common health disability in Australia, affecting one in six individuals to varying degrees (Access Economics, 2006). For a significant proportion of these individuals, their hearing loss is a result of cumulative exposure to loud sound. Known as noise-induced hearing loss (NIHL), it is one of the leading forms of workplace injury (Nelson et al, 2005). It is characterised by a permanent sensorineural hearing loss, typically with a notch at 3-6 kHz, and often occurs in association with other symptoms such as tinnitus (Axelsson & Sandh, 1985; Bergström & Nyström, 1986). The sensorineural loss, which is due to damage to the auditory hair cells in the cochlea, is the result of a combination of the sound pressure level, the duration of exposure, and the frequency of exposure (Kurabi et al., 2016).

According to Australian workplace health and safety standards, if noise levels exceed 85 dB $L_{Aeq}$ over an 8-hour work day, exposure time should be halved for every 3 dB increase to minimise hearing injury in workers (Standards Australia, 2005). There is discussion as to whether the same standards should apply in the music industry. Some argue that because music is not steady-state broadband industrial noise, but rather highly variable in terms of its dynamic range and frequency components, it may be appropriate to develop music-specific exposure standards that consider these differences (Staff-AES, 2006). Nevertheless, the 85 dB/8-hour exposure limit is the most commonly adopted damage-risk criterion, and there is ample evidence that musicians and those regularly exposed to loud music are at increased risk of hearing injury and NIHL (Patel, 2008; McIlvane, Stewart & Anderson, 2012; Pouryaghoub, Mehrdad, Pourhosein, 2017).

Studies of sound exposure of musicians have demonstrated that sound levels in the music industry regularly exceed workplace limits and have the potential to do harm
For classical musicians, on-stage sound levels of up to 111 dBA have been recorded (Camp & Horstman, 1992), with individual exposure varying greatly based on genre and positioning (O’Brien, Wilson & Bradley, 2008). High sound levels at pop/rock concerts have also been found, with 100 dBA levels common (Yassi et al., 1993; Opperman et al., 2006; Einhorn, 2006). At this level of exposure an individual’s daily noise limit is reached within just 15 minutes. The potential for high levels of exposure extend to rehearsal spaces, with one study finding rock musicians experienced levels between 90 and 96 dBA in this environment (McIlwaine et al., 2012).

Kähäri et al. (2003) estimated that some 74% of musicians experience at least one symptom of hearing injury, be it hearing loss, tinnitus, hyperacusis, distortion or diplacusis. Tinnitus in particular is reported to be common in musicians, with estimates ranging from 17% to 54%, of musicians, whereas the incidence of tinnitus in the general population is around 10% (see review by Patel, 2008; Homes & Padgham, 2011). However, conflicting results have also been reported, with some studies reporting minimal impact of music upon hearing thresholds, whilst others report significant evidence of risk (Karlsson, Lundquist & Olaussen, 1983; Axelsson & Lindgren, 1981; Cunningham et al., 2006). More recently, it has been reported that there may be damage from noise/music exposure without the presence of a hearing threshold shift, indicating that musical exposure can lead to degradation of the hearing pathway when over-exposure occurs (Kujawa & Liberman, 2009; Schaette & McAlpine, 2011; Otsuka et al., 2016).

In addition, symptoms such as tinnitus or permanent hearing loss can lead to secondary effects on quality of life such as depression, anxiety, or social isolation (Strawbridge et al., 2000; Mohamad, Hoare & Hall, 2016). For a musician, the effects of NIHL impact both on their professional and recreational pursuits, leaving many feeling a
sense of detachment from, or fear towards music. For instance, Størmer et al., 2015 found that 22.7% of rock musicians with tinnitus had considered quitting their profession simply due to its impact. Furthermore, Wills and Cooper (1988) reported jazz and pop musicians rated the health consequences of heavily amplified music as their sixth most significant work-related stress. With this in mind, it is imperative that musicians, who are at greater risk of hearing damage because of their high exposure levels, are offered appropriate and targeted audiological care, to assist them in making informed choices about hearing protection solutions.

Standard commercial hearing protectors, such as those designed for the workplace, are in general inappropriate for use by musician clientele. The common foam earplug, for example, can both over-attenuate and distort the musical sound, muffling high frequencies more so than lows, making it difficult for musicians to ensure the quality of their performance (Chasin, 1996; Chasin, 2009). To this end, musicians’ hearing protectors (MHP) have been developed to attenuate sound as evenly as possible across audible frequencies (Killion, 1988). In custom-moulded earplugs, this is achieved firstly by use of a hollow sound-bore in the centre plug, which acts as an acoustic mass. A thin diaphragm, or filter, is then attached to the external portion of the plug, whose stiffness helps dictate the degree of attenuation offered by the hearing protector, typically 9-10, 15 or 25 dB. When the earplug is inserted into the musician’s ear, their natural canal resonance is lost, yet the combination of both acoustic mass and filter help compensate for this and aid in achieving the flat attenuation (Killion, 1988).

Research has found the use of hearing protection by musicians to be consistently low in spite of many advances in technology (Laitinen & Poulsen, 2008; O’Brien, Ackermann & Driscoll, 2014). A study of 429 German symphony musicians for example, showed that even though 82.6% of musicians were aware of custom MHP, just 8.4% used
them during rehearsals and only 7.2% reported using them ‘often’ or ‘very often’ during a performance (Zander, Spahn & Richter, 2008). Dissatisfaction with hearing protectors often hinges upon issues such as impediment to their performance, disengagement from other instruments on stage, physical discomfort or distortion of sound due to occlusion of the ear canal (in which low frequency sounds become ‘trapped’ in the ear canal creating an audible echo) (Laitinen, 2005; Killion, 2012; O’Brien et al., 2014). However, additional factors such as training, audiological support and acclimatisation may have a significant, positive impact (Huttunen, Sivonen & Poykko, 2011; Casali & Lee, 2017).

Although there is a considerable literature on the technical aspects of MHP and barriers to their use, the focus has tended to be on the role of musicians in using MHP, rather than hearing professionals in recommending and/or counselling on their use. For this reason, our study focus was to investigate the role of the hearing healthcare sector, including both clinicians and manufacturers, in relation to musicians and MHP. More specifically, we were interested in understanding the standard of hearing care delivered to musicians in Australia, any variation in delivery, and the extent to which the practices of manufacturers and clinicians overlap. To achieve these aims, two exploratory surveys were developed, one for audiologists and one for manufacturers experienced in the creation or delivery of custom MHP in Australia.

### 3.3 METHODS

This study was conducted under the ethics approval and oversight of the University of Melbourne’s Human Ethics Sub-Committee.
3.3.1 Materials

Two survey instruments were developed; one for use with audiologists who were experienced in fitting MHP, and a second for use with manufacturers of MHP in Australia. For the purpose of this study, MHP referred to any custom-made product fit with a filter designed to give the wearer flat attenuation of sound. The audiologists’ survey covered technical issues such as impression technique and materials, as well as areas of professional practice, such as protocols and practitioner confidence. The manufacturer survey focused on the company’s methods of producing and verifying MHP, as well as their recommendations for audiologists on technical aspects. Both surveys included open- and closed-response items to encourage dialogue on the topic, and the questions addressed in this paper are shown in Appendices 1 and 2.

3.3.2 Procedure

Each survey was delivered to participants via an online survey platform (SurveyGizmo, Boulder, Colorado). Prior to completing the survey, participants were provided with information about the purpose of the study and advised that all responses would be kept confidential. Informed consent was then obtained from each respondent. Although participants were not required to provide any identifying information in the survey, all contact information (e.g., email addresses) which could be used to identify participants was stored separately from the survey responses to ensure confidentiality and privacy for all audiologists and manufacturer representatives. No inducements or rewards were provided to participants.
3.3.3 Recruitment

Audiologists were recruited via email invitation sent directly to hearing clinics throughout Australia. A copy of the link to the survey was also sent to 2500 members of Audiology Australia via the organisation’s e-newsletter. The five manufacturers of MHP in Australia were identified, and all were invited to participate individually via email. Follow-up phone contact was made where required.

3.3.4 Participants

Thirty-one audiologists responded to our invitation and completed the online survey (male = 41.9%, female = 58.1%). Age ranged from 26 to 64 years (mean = 38.7, SD = 11.8) with an average of 12.9 years’ clinical experience (range = 1 – 40 years). Just under one-third of the participants identified their role as management, and three as researcher. Previous musical experience was relatively high, with 77.4% having learnt an instrument at some stage, and almost half (48.4%) had performed professionally or semi-professionally. Most audiologists worked in metropolitan clinics (74.2%), while the remainder worked in a rural setting. Around one-third of the audiologists reported that there was a pre-existing relationship between their clinic and a MHP manufacturer, and four participants had a formal relationship with a professional music body (such as an orchestra.

Four of the five manufacturers approached agreed to be involved in our study, and the survey was completed by a company representative nominated by the manufacturer. Each manufacturer confirmed prior to involvement their engagement in the music industry and experience with providing MHP. Each manufacturer had experience manufacturing at least one type of MHP, but for the purposes of this study, the focus was
on custom-moulded, filtered MHP only. The manufacturers’ average years of involvement in making MHP was 22.4 years (range = 11 – 31 years). Two of the companies had connections with music-related bodies, such as hearing health organisations or orchestras.

3.3.5 Data Analysis

Descriptive statistics were used to further explore answers to closed response items from the survey questionnaires (appendices 1 and 2). For open-ended response items, answers were coded into appropriate categories and these were ranked in order of occurrence for each question. In order to investigate if years of clinical experience or previous musical training (semi-professional or professional) influenced any of the audiologists’ response outcomes, Pearson’s and likelihood ratio chi-squared tests were used.

3.4 RESULTS

3.4.1 Audiologist survey

3.4.1.1 Professional practice

The majority of audiologists felt confident in their ability to provide hearing care for musicians, with 27 (87.1%) reporting moderate or high confidence, and only four expressing slight confidence in the task. Despite this, 25 participants (80.7%) said they would find an upskilling course on the topic of musicians’ hearing care helpful to some degree, whilst six did not.
Audiologists were asked if a protocol for the hearing care of musicians was established in their clinic. While nine respondents (29%) indicated this was so, the description of these protocols ranged from guidance on impression technique to inclusion of extended diagnostic assessments. To clarify this, audiologists were asked to indicate which assessments were routinely included in their test battery when assessing musicians for hearing protectors (see table 1). By far the most common procedure was otoscopy, included by all respondents, followed by pure-tone-audiometry (PTA) up to 8 kHz (performed by 11 audiologists (35.5%)). Of these, seven requested a period of relative silence prior to the initial appointment. A further four audiologists who did not perform PTA also requested a period of relative silence prior to the appointment. Across the 11 audiologists the period requested ranged from 12 - 48 hours (mean = 26).

Table 1. Clinical procedures routinely included in audiologists’ test battery for musicians.

<table>
<thead>
<tr>
<th>Assessment Type</th>
<th>Proportion of Audiologists (n=31)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>n</td>
</tr>
<tr>
<td>Otoscopy</td>
<td>31</td>
</tr>
<tr>
<td>Pure Tone Audiometry (PTA)</td>
<td>11</td>
</tr>
<tr>
<td>Tympanometry</td>
<td>8</td>
</tr>
<tr>
<td>Speech Discrimination</td>
<td>4</td>
</tr>
<tr>
<td>Extended High Frequency PTA</td>
<td>1</td>
</tr>
<tr>
<td>Speech in Noise Discrimination</td>
<td>1</td>
</tr>
<tr>
<td>Acoustic Reflexes</td>
<td>1</td>
</tr>
<tr>
<td>Oto-acoustic Emissions</td>
<td>-</td>
</tr>
<tr>
<td>Loudness Discomfort Levels</td>
<td>-</td>
</tr>
</tbody>
</table>
There was considerable variation in how musicians obtained their MHP from audiologists. Sixteen clinicians (51.6%) routinely fitted earplugs in an appointment, while 13 (41.9%), did not, delivering them either over-counter or via post. The remaining two audiologists indicated that they would choose their delivery method based on the client’s preference. Follow-ups were uncommon with just five audiologists making further contact with the client via phone, email or appointment to check progress.

Provision of counselling on hearing protection for musicians was routinely carried out by 23 clinicians. Most of them \((n = 16)\) conducted this through informal discussion with the client, three by handing out instructional leaflets, and four using both methods. The topics most frequently mentioned during counselling were education about sound exposure \((n = 13)\) and hearing conservation practices \((n = 6)\).

Verification of the MHP, in which the attenuation provided by the earplugs was objectively measured, was routinely performed by six audiologists, all of whom compared pure-tone hearing thresholds with and without the earplugs in situ. Use of real-ear-measures was mentioned by two audiologists; however, both noted difficulties with this method of verification and commented on its lack of reliability. An additional two respondents indicated verification would only be undertaken if issues arose. Validation, in which the subjective fit of the hearing protectors was assessed, was routinely carried out by four audiologists; however, only one outlined a procedure for this beyond informal discussion.

### 3.4.1.2 Technical aspects of musicians’ hearing care

Audiologists were asked to indicate which method of impression taking they chose to use in preparation for making custom MHP. As shown in table 2, the most
common method was for the jaw to remain closed and stationary, although there was wide variation in responses. Preference for the material used for the otoblock (a safety dam inserted into the ear canal prior to impression taking) was closely divided between cotton and foam, as was the canal length of the MHP between medium and long (see table 2). In terms of viscosity of the impression material, high viscosity was favoured, with 41.9% preferring to use this when taking MHP impressions. For the earplug, the majority of audiologists (80.6%) preferred a soft silicon to be used, with a moderate density, or ‘shore’ 40, being favoured by 61.3%. It is worth noting that one clinician preferred their earplug to be made of hard acrylic, and another five were unsure as to their preference. Management features, such as removal pins and coloured tips for identification, had been ordered in the past by 80.6% of audiologists, with neck-cords ($n = 10$) and removal pins/handles ($n = 18$) being the most popular choices.

Audiologists were asked to indicate which level of hearing protection they most frequently prescribed. The most commonly prescribed attenuation was 15 dB ($n = 13$) followed by the highest attenuation, 25 dB ($n = 8$), only two audiologists preferred $\leq 10$ dB. Just over one in five audiologists ($n = 7$), indicated that the degree of attenuation was too dependent on the instrument to say and the remaining audiologist was unsure. Respondents were invited to elaborate on the attenuation level they would recommend for particular listening situations or instruments, and responses were coded into one of 12 categories. As can be seen in table 3, a small amount of attenuation ($\leq 10$ dB) was most often recommended for vocalists or acoustic settings but was otherwise rarely prescribed. Most audiologists indicated they would prescribe a moderate degree of attenuation for ‘most’ situations, and also for voice and classical settings. The highest amount of attenuation, $\geq 25$ dB, was most commonly recommended for percussionists and amplified listening situations.
Table 2. Clinician and manufacturer preferences for the making of musicians’ hearing protectors.

<table>
<thead>
<tr>
<th></th>
<th>Audiologists (n=31)</th>
<th>Manufacturers (n=4)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Impression Technique</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Closed jaw, stationary</td>
<td>45.2</td>
<td>25</td>
</tr>
<tr>
<td>Open jaw, stationary</td>
<td>6.5</td>
<td>25</td>
</tr>
<tr>
<td>Open jaw, with motion</td>
<td>9.7</td>
<td>25</td>
</tr>
<tr>
<td>Open jaw, with bite-block</td>
<td>25.8</td>
<td>-</td>
</tr>
<tr>
<td>Other</td>
<td>12.9</td>
<td>-</td>
</tr>
<tr>
<td>No recommendation</td>
<td>-</td>
<td>25</td>
</tr>
<tr>
<td>Impression Material Viscosity</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Low</td>
<td>29</td>
<td>25</td>
</tr>
<tr>
<td>Medium</td>
<td>NA</td>
<td>25</td>
</tr>
<tr>
<td>High</td>
<td>41.9</td>
<td>25</td>
</tr>
<tr>
<td>Unsure</td>
<td>29.1</td>
<td>25</td>
</tr>
<tr>
<td>Otoblock</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cotton</td>
<td>54.8</td>
<td>0</td>
</tr>
<tr>
<td>Foam</td>
<td>41.9</td>
<td>75</td>
</tr>
<tr>
<td>Either</td>
<td>3.2</td>
<td>25</td>
</tr>
<tr>
<td>Earplug Canal Length</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Short</td>
<td>0%</td>
<td>0</td>
</tr>
<tr>
<td>Medium</td>
<td>41.9</td>
<td>0</td>
</tr>
<tr>
<td>Long</td>
<td>48.4</td>
<td>100</td>
</tr>
<tr>
<td>Unsure</td>
<td>9.7</td>
<td>0</td>
</tr>
</tbody>
</table>

Furthermore, we investigated which instruments presented the ‘most difficulty’ when fitting MHP for musicians. Several audiologists (n=9) responded by referring to the occlusion effect, e.g., “anything with huge occlusion effects”, and the three instruments

1 This manufacturer responded with “Other: Neutral impressions going past the second bend,” which for the purposes of this survey was classified as closed, stationary.
2 This option was not provided in the audiology survey.
most commonly nominated as most difficult were those at highest risk of the occlusion effect, i.e. voice \((n = 10)\), brass \((n = 5)\) and wind \((n = 3)\).

Table 3. The situations and instruments for which audiologists most commonly recommend each level of attenuation.

<table>
<thead>
<tr>
<th></th>
<th>(\leq 10) dB</th>
<th>15 dB</th>
<th>(\geq 25) dB</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Situations</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Most</td>
<td>- 29%</td>
<td>9.7%</td>
<td>-</td>
</tr>
<tr>
<td>Amplified</td>
<td>- 29%</td>
<td>9.7%</td>
<td>-</td>
</tr>
<tr>
<td>Acoustic</td>
<td>22.6%</td>
<td>12.9%</td>
<td>-</td>
</tr>
<tr>
<td>Classical</td>
<td>9.7%</td>
<td>19.4%</td>
<td>-</td>
</tr>
<tr>
<td>Practice</td>
<td>16.1%</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Solo</td>
<td>6.5%</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td><strong>Instruments</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Percussion</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Voice</td>
<td>32.3%</td>
<td>16.1%</td>
<td>-</td>
</tr>
<tr>
<td>Guitar</td>
<td>3.2%</td>
<td>6.5%</td>
<td>6.5%</td>
</tr>
<tr>
<td>Brass</td>
<td>-</td>
<td>6.5%</td>
<td>3.2%</td>
</tr>
<tr>
<td>String</td>
<td>3.2%</td>
<td>3.2%</td>
<td>-</td>
</tr>
<tr>
<td>Rarely Prescribed</td>
<td>32.3%</td>
<td>-</td>
<td>9.7%</td>
</tr>
</tbody>
</table>

In an open response item, audiologists were asked what they perceived to be the main barriers to musicians using MHP (see table 4). Overwhelmingly, the impact of MHP on the musical experience was reported, followed by a lack of education and awareness and cost.

### 3.4.1.3 Post-hoc analyses

Chi-squared tests were performed to investigate if the audiologists’ years of clinical experience or previous musical training had affected the survey responses. First, respondents were split into two groups based on experience, those with less than the
median of eight years’ clinical experience (n=15), and those with eight or more years’ experience (n=16). Pearson Chi-squared tests indicated that experienced clinicians were more likely to request a period of relative silence prior to seeing a musician (than non-experienced clinicians (62.5% vs 13.3%), $X^2(1) = 7.89$, $p=0.005$. Likelihood ratio tests indicated that more experienced clinicians were more open to involvement in an upskilling course on the topic (than less experienced clinicians (93.8% vs 66.7%), $X^2(1) = 3.87$, $p=0.049$. They were also significantly more likely to favour a moderate (15 dB) degree of attenuation when compared to less experienced clinicians (68.8% vs 13.3%), $X^2(1) = 12.19$ $p=0.007$.

Table 4. Audiologist perceived barriers to use of musicians’ hearing protectors.

<table>
<thead>
<tr>
<th>Barriers</th>
<th>Proportion of Audiologists (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Impact on music experience</td>
<td>54.8</td>
</tr>
<tr>
<td>Lack of Education</td>
<td>35.6</td>
</tr>
<tr>
<td>Cost</td>
<td>25.8</td>
</tr>
<tr>
<td>Over-attenuation</td>
<td>19.3</td>
</tr>
<tr>
<td>Occlusion</td>
<td>16.1</td>
</tr>
<tr>
<td>Stigma</td>
<td>16.1</td>
</tr>
<tr>
<td>Poor fit/comfort</td>
<td>12.9</td>
</tr>
<tr>
<td>Appearance</td>
<td>9.7</td>
</tr>
<tr>
<td>Lack of acclimatisation</td>
<td>6.5</td>
</tr>
<tr>
<td>Motivation</td>
<td>6.5</td>
</tr>
</tbody>
</table>

While no other results reached significance, there was a general trend observed in many responses, with more experienced clinicians more likely to perform PTA (43.8%) vs 26.7%), verify earplugs (37.5% vs 13.3%), counsel on use (37.5% vs 13.3%) and follow-up on progress (25% vs 6.7%, than those with less experience. Experienced audiologists were also more likely to use cotton as their otoblock as opposed to foam
(62.5% vs 46.7%), and 93.8% had ordered management features in the past, as opposed to 66.7% of clinicians with less experience.

Audiologists were then divided into two groups, those who had professional or semi-professional music experience ($n = 15$) and those who did not ($n = 16$). For this division, no significant differences were seen on the closed response items, but again several trends were noted; clinicians with musical experience were more likely to perform PTA (46.7% vs 25%), request a period of relative silence prior to testing (46.7% vs 25%) and follow-up on progress (26.7% vs 6.3%). Clinicians with musical experience were also more likely to use a method of open-mouth impression taking (53.3% vs 31.3%), and more likely to state that preferred earplug filter depended on the instrument played (40% vs 12.5%). Finally, audiologists with musical experience were less likely to fit earplugs in an appointment than those without experience (40% vs 62.5%).

### 3.4.2 Manufacturer survey

The responses to the closed items on the manufacturer survey are presented in table 2. For two of the items the recommendations offered by manufacturers to clinicians seemed to be in agreement. These were for the use of otoblock, with three companies recommending foam and one recommending either foam or cotton, and the earplug canal length. For the latter, all manufacturers indicated they would recommend a long canal length for their custom MHP. Items over which they were not in agreement however, were the impression technique recommended by manufacturers and the viscosity of the impression material to be used. As can be seen in table 2, a different impression technique was recommended by each manufacturer excluding one that indicated they had no formal recommendation for audiologists on this process. Similarly, a different response was seen
from each manufacturer as to the viscosity of the material recommended for taking impressions, with one commenting that they had no specific recommendations for audiologists.

Responses to open survey items revealed that manufacturers placed a great emphasis on the accuracy of impression-taking by the audiologist in order to achieve a well-fitting earplug. For example, “The outcome really depends on the quality that you start with. Good impressions are the key,” and “as long the imprint is made by a pro.” When asked what advice they might give if the occlusion effect was a problem for a client, three manufacturers made reference to optimising the canal length by extending it beyond the second bend, for example,

“Provide ‘full shell’ neutral impressions going well past the second bend free from voids. Occlusion reduction can be done by canal length optimisation and selecting the correct filter for the specific application.”

However, one manufacturer provided the opposite response, suggesting that canal length be shortened.  

Manufacturers were also asked if, and what sort of, recommendations were available to audiologists regarding choosing an appropriate degree of attenuation. One company recommended “on-site noise testing” be conducted and another suggested that the main genre of exposure should determine the filter strength. The remaining respondents either gave no recommendations or requested the audiologist contact them directly for support. In terms of design options for management and handling of MHP,

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3 A request was made by the author to clarify the response and the answer was repeated.
three of the four companies offered style variations such as neck cords, handles or removal lines.

3.5 DISCUSSION

By surveying audiologists and manufacturers of hearing protectors for musicians, this study has uncovered a number of revealing insights into the practice of providing hearing care for musicians, a facet of the hearing industry that has been largely unexplored until now. Overall, the main finding was that whilst audiologists reported high confidence in providing care for musicians, there was considerable variation in the way that care was provided. Despite the vast majority of audiologists (87%) feeling confident in their ability to care for musicians, 81% expressed interest in further training on the topic – an encouraging finding which suggests that clinicians are eager to know more about this specialised practice area:

“When I said I’m ‘highly confident’ I’m very aware there’s A LOT more I could learn on this specific topic and would love a CPD [continuing professional development] event covering this.”

There was also variation in responses to the manufacturer survey, with great diversity in both the manufacturing of MHP and recommendations by manufacturers to audiologists on their preferred impression technique.

It was clear that not all audiologists associated an impression appointment for MHP with the need for a hearing assessment. In fact, PTA was conducted by just 35% of audiologists prior to advising on hearing protection. While the reasons behind this low figure were not directly explored, open-ended responses shed light on assumptions that
PTA was not wanted by clients, ‘Musicians are often poor and do not want a hearing test as well as ordering the muso earplugs.’ It could be argued that providing hearing protection does not require knowledge of the client’s hearing thresholds. However, we would suggest that, ideally, MHP should be provided as part of a holistic package of hearing healthcare that covers all aspects of musicians’ hearing wellness. In this case, monitoring the impact of noise exposure via audiometry should be regarded as a crucial element in the overall care of musicians’ hearing. In some circumstances, time and/or cost pressures may exist that do now allow for a full hearing test to occur. In such instances, oto-acoustic emissions could be a viable tool for hearing screening, yet these were very rarely performed by our cohort.

The inclusion of extended diagnostics in the test battery for musicians was also rarely seen. Common tests such as speech discrimination were only performed by 13% of audiologists, and acoustic reflexes, which are less common generally, were only performed by just one audiologist. The testing of extended high frequency hearing beyond the traditional speech frequency range was also uncommon, again only performed by one audiologist in the sample. Testing these frequencies, however, could arguably be of great value to the care of a musician; not only are they implicated in detecting early onset NIHL (Rocha, Atherino & Frota, 2010; Lüders et al., 2014; Mehrparvar et al., 2014), these frequencies also carry the musical overtones necessary to perceive the quality and timbre of music (Emiroglu & Kollmeier, 2017). For a client wanting to experience the full range of sounds, not just speech frequencies, this information could both guide and inform a hearing conservation plan, yet this is not being performed at the clinical level.

For delivery of MHP, audiologists were divided, with half providing the earplugs routinely in an appointment and the remainder either posting out or leaving for client collection. We would argue that these appointments are crucial as they provide both
PARTIES WITH AN OPPORTUNITY FOR COUNSELLING, MHP FIT-TRAINING, AND MEASUREMENTS OF VALIDATION AND VERIFICATION. RESEARCH SHOWS THAT FIT-TRAINING FOR USERS OF CUSTOM HEARING PROTECTORS IMPROVES ATTENUATION CONSISTENCY AND FIT RELIABILITY (CASALI & LESS 2017; TUFTS, JAHN & BYRAM, 2013) IN THE SAMPLE STUDIED HERE, IT WAS ENCOURAGING TO NOTE THAT HALF THE AUDIOLIGISTS PROVIDED FIT-TRAINING, BUT MEASURES OF OBJECTIVE VERIFICATION OR SUBJECTIVE VALIDATION TO ENSURE SUCCESSFUL INSERTION WERE ONLY PERFORMED BY 19% AND 13% OF AUDIOLIGISTS RESPECTIVELY. ONE POSSIBLE REASON FOR THIS CAN BE INFERRED FROM THE SURVEY COMMENTS, SUGGESTING CLINICIANS HAD LOW CONFIDENCE IN THE CURRENT METHODS OF EARPLUG VERIFICATION, WITH SEVERAL RESPONDENTS HIGHLIGHTING FRUSTRATION AT THE LACK OF PRECISION IN PTA COMPARISONS AND PROBE-TUBE MEASURES. SIMPLY STATED, ONE RESPONDENT COMMENTED, “WE NEED BETTER SOLUTIONS THAN WHAT WE CURRENTLY HAVE.”

ANALYSING SURVEY RESPONSES BY CLINICAL EXPERIENCE DID SHOW TRENDS TOWARDS A HIGHER LEVEL OF CARE IN THOSE WITH MORE EXPERIENCE IN THE HEARING INDUSTRY. THIS WAS PARTICULARLY EVIDENT WITH EXPERIENCED AUDIOLIGISTS MORE LIKELY TO REQUEST A RELATIVE PERIOD OF SILENCE PRIOR TO TESTING, PERFORM PTA, VERIFY EARPLUGS, COUNSEL ON HEARING PROTECTION AND FOLLOW UP CLIENTS. THEY WERE ALSO MORE LIKELY TO BE CONSERVATIVE ON THE TOPIC OF OVER-ATTENUATION, FAVOURING THE MEDIUM STRENGTH FILTER OF 15 dB FAR MORE THAN INEXPERIENCED CLINICIANS. A SIMILAR BIAS TOWARDS HIGH-LEVEL CARE IN THOSE WITH MUSICAL EXPERIENCE WAS ALSO EVIDENT IN THE RESULTS. AGAIN, THESE CLINICIANS WERE MORE LIKELY TO REQUEST A RELATIVE PERIOD OF SILENCE, PERFORM PTA AND FOLLOW-UP ON PROGRESS MORE THAN CLINICIANS WITHOUT MUSICAL EXPERIENCE. THEY WERE ALSO MORE LIKELY TO USE OPEN-MOUTH IMPRESSION TECHNIQUES, METHODS KNOWN TO HELP CREATE A TIGHTER, MORE CLOSELY FITTED EARPLUG (PIRZANSKI, 2006). THEY WERE ALSO MORE LIKELY TO COMMENT THAT CHOOSING THE STRENGTH OF ATTENUATION DEPENDED HEAVILY ON THE INSTRUMENT THE MUSICIAN PLAYED, PERHAPS REFLECTING THEIR DEEPER KNOWLEDGE OF MUSIC PRACTICE. SURPRISINGLY, WE FOUND THAT AUDIOLIGISTS WITH MUSICAL
experience were less likely to personally fit hearing protection to clients, and more likely to post them to the client. It is difficult to explain this trend, but it could be seen as an indication that the clinicians with musical experience were confident in their clients’ ability to use the protection, or it could reflect an assumption on the part of the audiologists that musicians are less able to afford the time or money for additional appointments.

On surveying manufacturers, it was clear that great responsibility was placed on the audiologist to create a quality ear impression. However, when asked how this should be achieved, a range of disparate responses were recorded. For technical issues such as otoblock use or canal length of the earplug, almost all agreed on the same response items (foam and long respectively). Yet for key steps, such as impression technique or the viscosity of the impression material, factors known to influence the fit of the final earplug (Pirzanski, 2006; Maltby, 2016), not one manufacturer agreed with any of the others. Audiologists also showed wide variation in how they went about preparing for MHP. This manufacturer-audiologist divide, which leaves many audiologists unsure of how to proceed, has been noted previously (Hurley 2015).

Audiologists most frequently reported difficulty fitting MHP for musicians who played instruments at high risk of the occlusion effect, particularly those that involve vocalisation as a by-product of playing, i.e., voice, brass and wind. The intensity of the occlusion effect is directly linked to the canal length and seal of the musicians’ earplug (Killion, 2012). Earplugs with a shallow fit provide greater room for amplification of internalised low-frequency sounds, often interpreted as over-powering and intolerable to the musician. This can and has been demonstrated to lead to earplug rejection (Laitinen & Poulsen, 2008). However, it has also been documented that the occlusion effect can be managed (at least in part) with insertion of the earplug beyond the second bend of the ear
canal (Killion, 2003; Lee, 2011; Pirzanski, 2006). It is concerning then, that although most manufacturers recommended a long canal length in our survey, almost half of audiologists routinely ordered medium-sized canal lengths. As a result, the likelihood of musicians experiencing the occlusion effect is increased, as is their risk of rejecting their hearing protectors.

When considering the results of this study the potential for response bias should be taken into account. The sample of audiologists who completed the survey included a high proportion of musically experienced clinicians. The survey content itself seems to have attracted audiologists with a personal interest in the study aims, and as a result the conclusions drawn may not be generalisable to the broader audiologist community. Furthermore, the small sample size likely contributed to the paucity of statistically significantly results obtained, although trends in responses were evident.

3.6 CONCLUSION

Overall, this study aimed to investigate the standard of hearing healthcare care provided to musicians in Australia by investigating both clinical services provided by audiologists, and recommendations of manufacturers of MHP. Data from this study may be helpful in identifying gaps in information, methods and professional training that might negatively influence outcomes of protection use by musicians. The results of the surveys suggest that there are multiple ways in which hearing care professionals might inadvertently be doing so. Despite the existence of excellent resources to guide MHP practice (e.g. Chasin, 2009), it is not necessarily evident that such tools have influenced practice at the clinic level. These results reveal the need for implementation of findings and provision of training at the clinical level. In fact, the results of this study suggest that
the majority of clinicians would welcome further training opportunities that might help inform their care of musicians. As an industry, if we wish to support musicians in the use of MHP and conservation of their hearing, then it would seem we need to start with the support of those providing them with this care.

3.7 ACKNOWLEDGEMENTS

The results of this study, *Caring for musicians’ ears: Insights from clinicians and manufacturers reveal need for evidence-based guidelines*, were presented at the National Hearing Conservation Association’s annual research conference in Texas, USA, February 25, 2017. The authors thank the association for their support in attending the conference. The authors acknowledge the financial support of the HEARing CRC, established and supported under the Australian Government’s Cooperative Research Centres Program and the Australian Government Department of Health. The authors would like to also thank Ian O’Brien, PhD, Dominic Power and Caitlin Barr, PhD for their early contribution.
REFERENCES


CHAPTER 3 RESULTS


You are the music, while the music lasts.

~ T.S. Elliot
PREVENTING HEARING INJURY IN MUSICIANS: EXPLORING PERSON-CENTRED CARE IN THE PRACTICE OF AUDIOLOGY FOR MUSICIANS

The following paper is incorporated in its entirety in this chapter, inserted as submitted, with the exception of formatting changes to headings, tables, figures and references to maintain consistency throughout the thesis:

Manuscript accepted for publication


**Aim:** to investigate whether the use of, and satisfaction with, MHPs is influenced by the specific treatment delivered to musicians by audiologists.
4.1 ABSTRACT

Objective: To reduce the risk of hearing injury, musicians are often recommended custom-made musicians’ hearing protectors (MHP). Studies report benefits of use however, many still report challenges leading to relatively low uptake and inconsistent usage. Person-centred approaches to health have been shown to improving patient outcomes; and these principles may be translatable to musicians’ hearing care. The aim was to investigate if use of, and satisfaction with, MHP is influenced by the treatment delivered to musicians by audiologists. Design: Participants were randomly allocated to one of four conditions that varied in extent of person-centred care. Study Sample: Forty-two musicians with an interest in purchasing MHP were recruited. Results: Satisfaction with MHP was high overall and users reported a reduction in incidence of tinnitus. Participants reported few issues related to sound quality, however insertion difficulty was the main problem reported. Only one musician self-identified the need for alterations to their MHP. Conclusions: Adoption of person-centred approaches to MHP was not found to increase likelihood of use, however, satisfaction was high across all conditions. Importantly, the need for MHP alterations were clinician-identified during fit/follow-up appointments in most cases, which underscores the importance of including this component when providing audiological services to musicians.
4.2 INTRODUCTION

Due to their regular exposure to high sound pressure levels, many musicians risk sustaining hearing injury as a by-product of their profession (Jansen et al. 2009; Halevi-Katz, Yaakobi & Putter-Katz, 2015). Music-induced hearing injury (MIHI) can present as a variety of negative hearing symptoms, including hearing loss, tinnitus, hyperacusis (decreased sound tolerance), hearing distortion, and diplacusis (Kähäri et al. 2003). The latter can be particularly difficult for a musician because it results in the same sound being heard as two separate, unrelated pitches (Colin et al. 2016). Furthermore, each of these symptoms can result in secondary effects, impacting sleep quality, mental well-being and quality of life (Gomaa et al. 2014; Schecklmann et al. 2015; Störmer, Sorlie & Stenklev, 2017). For working musicians, these symptoms can also pose a barrier to their profession, often adversely affecting their ability to play in tune, perform or even enjoy music. As symptoms are often the result of damage accumulated over time, encouraging the use of healthy hearing behaviours at all stages of a musician’s career is therefore vital in the prevention of MIHI (Kujawa & Liberman, 2009; Eggermont, 2017).

To address the unique hearing needs of musicians, specialist musicians’ hearing protectors (MHP) were first introduced in the 1980s. These were designed to attenuate sound as evenly as possible across the audible spectrum, and reduce the spectral distortion introduced by traditional foam earplugs. Custom-made MHP are comprised of a silicon plug with a hollow sound bore, capped on the outer end with an attenuation filter (Killion, DeVilbiss & Stewart, 1988). These interchangeable filters vary in attenuation rating, from mild (e.g. 9 dB), through to strong (e.g. 25 dB). Many musicians report positive benefits from use of MHPs, including reduced experience of negative hearing symptoms and improved comfort in sound (Beach & O’Brien, 2017). Significant difficulties, however, are also reported, such as reduction in the ability to hear one’s own instrument or the ability to blend with other musicians in a
CHAPTER 4 RESULTS

performance (Laitinen, 2005). If not addressed, these difficulties may prevent consistent use, and are likely reasons underlying the low rates of usage reported by both orchestral and rock/pop musicians (Laitinen & Poulsen, 2008; Zander, Spahn & Richter, 2008; Halevi-Katz et al. 2015).

The typical path for a musician to obtain MHP is through an appointment with an audiologist. There are, however, no accepted guidelines as to how an audiologist should assess the need for, and/or proceed with fitting a MHP. As the audiologist is an integral part of customising the MHP for their client, their treatment may also impact the musician’s overall experience with their protectors. For instance, occlusion, a deleterious echo of one’s own voice heard loudly in the ears or head (Pirzanski, 2006) is a commonly reported problem with MHP, but this can be reduced through various techniques including use of tightly fitting plugs extending beyond the second bend of the ear canal. Furthermore, with proper training by an audiologist, the depth of insertion of hearing protectors can be greatly improved, resulting in more consistent sound attenuation - a benefit sustained over time (Toivonen et al. 2002; Tsukada & Sakakibara, 2008). With the lack of recommended guidelines, however, previous research indicates that both audiologists and manufacturers differ greatly in how they proceed with the creation and prescription of hearing protectors, suggesting examples of optimal care such as those described above, may not be industry-wide (McGinnity et al. 2018). It is therefore important to explore the impact audiological care related to MHPs has on outcomes, to see if satisfaction and usage can be improved from the outset.

To improve outcomes for musicians, an approach which considers their listening needs is likely to be beneficial. Person-centred care (PCC) – which approaches each individual uniquely in terms of needs and treatment – is associated with improved outcomes, such as satisfaction, adherence to recommendations, reduced anxiety for clients and families, and ultimately improved quality of care (Grenness et al. 2014). Regarding musicians and their use
of hearing protectors, it seems likely therefore, that an approach which incorporates PCC may also improve outcomes, especially those surrounding satisfaction with and adherence to recommendations of MHP usage. In a systematic review, Scholl et al. (2014) described six key activities in providing PCC: client information, client involvement, involvement of family/friends, client empowerment, physical support and emotional support, as well as key principles relating to clinician-client communication and understanding the client’s biopsychosocial perspective (Scholl et al. 2014; Park et al. 2018). Drawing upon these principles in audiology, we would expect that clients will report similar improved outcomes as have been seen more broadly in allied health professions.

One way to incorporate the principles of PCC into treatment for musicians is to utilise currently available tools in a novel way. For example, the Client Oriented Scale of Improvement (COSI) is a commonly used audiological tool used to facilitate conversation about the client’s biopsychosocial perspectives, providing a platform from which outcome evaluation (improvements in participation and residual disability) can occur (Dillon, James & Ginis, 1997). The COSI uses two steps: structured goal-setting with the client and a revisit of the goals post-intervention, thus, tailoring the intervention choices to the client’s personal goals. In its current format, the COSI is directed to conversations around hearing loss rehabilitation. It is person-centred in its provision of information, client involvement and support, and enhances overall clinician-client communication. Building upon this design, the authors sought to create a unique, musician-centred tool for the provision of PCC for musicians; the Musician-Oriented Scale of Improvement (MOSI).

The aim of this study was to evaluate if the provision of treatment tailored to musicians’ needs, would alter the outcomes of earplug satisfaction and usage. Secondarily, we aimed to investigate whether the MOSI, was an effective tool for enhancing PCC and improving outcomes for musicians. The overall hypothesis was that individuals receiving PCC-based
treatments, through the use of the MOSI or extended provision of information and diagnostics, would show greater use of and/or satisfaction with their hearing protectors, leading, ultimately, to greater protection of their hearing and prevention of MIHI.

4.3 METHODS

This study was conducted under the ethical oversight of the University of Melbourne’s Human Research Ethics Committee and adhered to the principles of the National Statement on Ethical Conduct in Human Research (NH&MRC 2015).

4.3.1 Participants & recruitment

Participants were recruited via word-of-mouth, advertising through local music industry organisations and through the University of Melbourne’s Audiology and Speech Pathology Clinic. Inclusion criteria included self-identification as a performing musician (i.e. professional or amateur) and a desire to purchase custom-moulded MHP. Participants were not compensated for their time, but the MHP were made available to them at cost price. A total of 44 musicians participated in the study, however, two did not complete the full protocol and their results were excluded from analysis.

4.3.2 Materials

4.3.2.1 MOSI

The MOSI is a single-page form designed by the authors to guide PCC with musicians. It is based closely on the COSI, a tool used to guide client-centred care (Dillon et al. 1997). It
consists of two sections, *listening situations* and *hearing protection goals*. For the first, the client lists all environments in which they would need or wish to use their MHP (e.g. in rehearsals), and in the second, up to five goals they would like to achieve through use of their MHP, e.g. *to not hear tinnitus after a rehearsal; or to be able to hear the other band members on stage*. At the follow-up appointment, the client is asked to estimate how often they had used the MHP in each listening situation (e.g. *Rehearsals: 80% of the time*), and to evaluate how well the MHP had met their hearing protection goals using a 5-point Likert scale, from *not at all* to *exceeded*. Any listening situation or goal not meeting the client’s expectations was reviewed with the clinician to prompt action where needed.

### 4.3.2.2 Questionnaires

Two questionnaires were created for the study, delivered online using survey platform, Survey Gizmo (Boulder, CO). The first was a pre-appointment questionnaire, covering the participant’s music history, hearing health and use of hearing protectors. The second was a self-guided exit interview covering the participant’s satisfaction with, and use of hearing protectors, sent after a minimum of two weeks use of the MHP. Each questionnaire used a combination of open and closed-response items to maximise the amount of detail the participant could provide.

### 4.3.3 Procedure

Informed consent was obtained from each musician prior to participation, after which they were randomly allocated to one of four treatment conditions: control, standard, person-centred and diagnostic. These conditions were designed to segregate key components of service that were considered capable of altering outcomes. To avoid clinician bias, participants were
also randomly allocated to one of three researchers/clinicians. Pre-appointment questionnaires were then delivered online and completed prior to attending the first appointment.

Table 1. Procedures included in the test battery for each condition

<table>
<thead>
<tr>
<th>Condition</th>
<th>Control (n=10)</th>
<th>Standard (n=11)</th>
<th>Diagnostic (n=9)</th>
<th>Person-centred (n=12)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Otoscopy</td>
<td>√</td>
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<tr>
<td>Tympanometry</td>
<td>√</td>
<td>√</td>
<td>√</td>
<td>√</td>
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<tr>
<td>Pure-tone audiometry</td>
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<td>EHF</td>
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<td>LiSN-S</td>
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<td></td>
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<tr>
<td>DPOAEs</td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fitting</td>
<td>√</td>
<td>√</td>
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<td></td>
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<tr>
<td>Verification</td>
<td>√</td>
<td>√</td>
<td>√</td>
<td></td>
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<tr>
<td>Validation (MOSI)</td>
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</table>

The components included in each treatment condition can be seen in Table 1. Otoscopy and tympanometry were performed in all treatment conditions to screen for external and middle ear pathology. Where appropriate, excess cerumen was removed prior to the first appointment via curette or suction. Pure-tone audiometry (.5, 1, 2, 3, 4, 6, 8 kHz) using the modified Hughson-Westlake method, was conducted in a sound-treated booth (AS/NZS 1269.4:2014), using an Affinity 2.0 audiometer (Interacoustics, Denmark), TDH-39P headphones (Telephonics Co., NY, USA), and EAR-Tone insert earphones in the presence of collapsing canals. When tested, extended high frequencies (EHF; 9, 10, 11.25, 12.5, 14 and 16 kHz) were performed using Koss R80 headphones. Speech discrimination in quiet was tested using AB words (Boothroyed, 1968), and speech discrimination in noise using the Listening in

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Spatialised Noise Sentences Test (LiSN-S; Cameron & Dillon, 2007). Finally, distortion product oto-acoustic emissions (DPOAEs) were undertaken using Interacoustics Titan for test frequencies 1, 1.5, 2, 3, 4 and 6 kHz.

In all treatment conditions, clinicians offered participants several choices in relation to the creation of their MHP. This included a choice of manufacturer\(^4\) (A or B), filter (Etymotic Research; Elk Grove, IL or ACS Pro; Banbury, UK), attenuation (Etymotic Research: 9, 15 or 25 dB; ACS Pro: 10, 15, 17, 20, 26, 27 or 31 dB), management aids (e.g. a neck cord or handle), and any requested cosmetic alterations (e.g. colouring or name engraving). Ear impressions were taken beyond the second bend of the ear canal, using two-part Widex Otoform-A/K, a hand-injected syringe and either foam or cotton otoblocks. For manufacturing, the length of canal was consistently ordered as long (beyond the second bend), and the density of the earmould was medium (Shore 40).

Earplugs were then either posted to the client or returned in a fitting appointment. Fitting appointments allowed for the clinician to check the comfort and fit of the earplug, provide insertion training and verification. Verification involved testing the participant’s hearing thresholds while wearing and not wearing earplugs in order to verify the level of attenuation across frequencies. Assessment of goal attainment using the MOSI was conducted by phone or email (determined by participant preference), and any presenting concerns were addressed by the clinician at the time of contact. Following a minimum of two-weeks earplug usage, participants were sent the exit questionnaire to complete online.

\(^4\) A price difference existed between manufacturer A and B, with earplugs from B being more expensive than manufacturer A.
4.3.4 Data analysis

All open-ended questionnaire responses were categorised and analysed thematically. Descriptive statistics were used to explore the data more broadly, and between-group comparisons of treatments were conducted using Chi-Square and Fisher’s Exact test.

4.4 RESULTS

4.4.1 Pre-appointment questionnaire

Participant details across treatment conditions can be seen in Table 2. Of the 42 participants, 27 were male, 14 female and one identified as other, with an average age of 30.4 years (range: 21-52, SD: 5.9). The majority worked either professionally full- or part-time in the industry (n = 22) with several holding formal music qualifications at a certificate/diploma (n = 4) or bachelor’s degree (n = 12) level. The most commonly performed genres were rock (n = 22), pop (n = 12) or electronic music (n = 11), however, many played across multiple genres (n = 26). As for instrument, guitar (n = 25), voice (n = 20), keyboard, bass guitar (n = 13) and percussion (n = 5) were most common, yet many identified as a multi-instrumentalist (n = 29).

The experience of hearing injury symptoms after work in music (e.g. rehearsal or performance) was common across the sample, with most participants reporting having experienced tinnitus. Tinnitus was experienced, irrespective of music work, frequently or always by seven, occasionally or sometimes in over two-thirds (n = 28), with the remaining seven having never experienced it. As shown in Table 3, only two individuals reported an absence of any of the listed injury symptoms. During the pre-appointment questionnaire, the overwhelming majority responded yes (n = 39) when asked if they believed their hearing to be at risk working as a musician, with only three participants unsure (see Table 3). The use of
hearing protection in music was high \((n = 39)\), yet frequency varied, with 13 using them \textit{frequently} or \textit{always}, a further 13 \textit{sometimes}, and 16 \textit{occasionally} or \textit{never}.

Table 2. Participant demographics across each treatment condition

<table>
<thead>
<tr>
<th>Condition</th>
<th>Control ((n = 10))</th>
<th>Standard ((n = 11))</th>
<th>Diagnostic ((n = 9))</th>
<th>Person-centred ((n = 12))</th>
<th>Totals (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age mean</td>
<td>32.5 (\text{(SD = 4.8)})</td>
<td>29.6 (\text{(SD = 3.2)})</td>
<td>29.33 (\text{(SD = 6.0)})</td>
<td>30.3 (\text{(SD = 8.2)})</td>
<td>30.3</td>
</tr>
<tr>
<td>Gender</td>
<td>Male 5 9 4 9 64.3</td>
<td>Female 5 2 5 2 33.3</td>
<td>Other - - - 1 2.4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Employment</td>
<td>Professional 3 5 7 7 52.4</td>
<td>Freelance 2 3 2 - 16.7</td>
<td>Amateur/recreational 4 2 - 3 21.4</td>
<td>Other 1 1 - 2 9.5</td>
<td></td>
</tr>
<tr>
<td>Performance Frequency</td>
<td>&lt;5 hrs/week 3 8 6 7 57.1</td>
<td>5-10 hrs/week 6 2 1 3 28.6</td>
<td>&gt;10 hours/week 1 1 2 2 14.3</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

When exploring the types of hearing protectors used during music work, a wide variety of styles were reported as having been worn in the past. As shown in Table 4, the main types were foam and non-custom, and for 15 of the participants, tissue/cotton-wool. Only four musicians had worn custom-made MHP in the past.
Table 3. Hearing injury and hearing protection usage across each treatment condition.

<table>
<thead>
<tr>
<th></th>
<th>Control (n = 10)</th>
<th>Standard (n = 11)</th>
<th>Diagnostic (n = 9)</th>
<th>Person-centred (n = 12)</th>
<th>Totals (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Hearing risk belief</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Yes</td>
<td>10</td>
<td>10</td>
<td>9</td>
<td>10</td>
<td>92.9</td>
</tr>
<tr>
<td>Unsure</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>2</td>
<td>7.1</td>
</tr>
<tr>
<td><strong>Previous earplug usage</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Yes</td>
<td>9</td>
<td>11</td>
<td>8</td>
<td>11</td>
<td>92.9</td>
</tr>
<tr>
<td>No</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>7.1</td>
</tr>
<tr>
<td><strong>Post work symptom</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tinnitus</td>
<td>9</td>
<td>10</td>
<td>7</td>
<td>8</td>
<td>80.9</td>
</tr>
<tr>
<td>Dullness</td>
<td>4</td>
<td>7</td>
<td>2</td>
<td>9</td>
<td>52.4</td>
</tr>
<tr>
<td>Blocked ears</td>
<td>2</td>
<td>3</td>
<td>1</td>
<td>4</td>
<td>23.8</td>
</tr>
<tr>
<td>Otalgia</td>
<td>2</td>
<td>3</td>
<td>1</td>
<td>0</td>
<td>14.3</td>
</tr>
<tr>
<td>Distortion</td>
<td>0</td>
<td>2</td>
<td>0</td>
<td>2</td>
<td>9.5</td>
</tr>
<tr>
<td>None</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>4.8</td>
</tr>
</tbody>
</table>

### 4.4.2 Selection of musicians’ hearing protection

A breakdown of the selection of hearing protection features ordered by participants can be seen in Table 5. For the make of the earplugs, manufacturer A was the most popular, ordered by 35 participants, as were Etymotic filters, chosen by 34. The most commonly ordered attenuation was the moderate level (15-17 dB), ordered by 19. Only three participants ordered the 25 dB filter, two of whom were drummers. Cosmetic alterations were common (n = 16), while management features were less frequently requested (n = 4).
Table 4. Styles of hearing protectors worn in the past by musicians.\textsuperscript{5}

<table>
<thead>
<tr>
<th>Hearing Protection</th>
<th>n</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Foam</td>
<td>31</td>
<td>73.8</td>
</tr>
<tr>
<td>Filtered, non-custom</td>
<td>23</td>
<td>54.8</td>
</tr>
<tr>
<td>Tissue/cotton-wool</td>
<td>15</td>
<td>35.7</td>
</tr>
<tr>
<td>Custom moulded</td>
<td>4</td>
<td>9.5</td>
</tr>
<tr>
<td>Custom vented</td>
<td>1</td>
<td>2.4</td>
</tr>
<tr>
<td>Electronic</td>
<td>1</td>
<td>2.4</td>
</tr>
<tr>
<td>In-ear-monitor</td>
<td>8</td>
<td>19</td>
</tr>
<tr>
<td>Custom in-ear-monitor</td>
<td>2</td>
<td>4.8</td>
</tr>
<tr>
<td>Earmuffs</td>
<td>2</td>
<td>4.8</td>
</tr>
</tbody>
</table>

Six participants required alterations: two for physical fit; three for attenuation reduction; and one for an increase in attenuation. Of these, only one self-advocated for adjustments, making contact with the audiologist post-fitting to increase their level of attenuation. This participant was part of the standard treatment condition. The remaining alterations were clinician-identified during the formal fit/follow-up that occurred during the patient-centred and diagnostic conditions. The two physical alterations were all identified during the fitting appointment of the diagnostic condition; one during verification finding a poor acoustic seal, and the second noting an inability to insert the earplug comfortably, while the three requiring attenuation reduction were identified in the follow-up component of the person-centred condition. None of the participants from the control treatment condition received or requested any alterations.

\textsuperscript{5} Multiple responses were allowed to this question
Table 5. Details of earplug customisation for each participant.

<table>
<thead>
<tr>
<th>Condition</th>
<th>Control (n = 10)</th>
<th>Standard (n = 11)</th>
<th>Diagnostic (n = 9)</th>
<th>Patient-centred (n = 12)</th>
<th>Totals (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Manufacturer</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>A</td>
<td>9</td>
<td>9</td>
<td>7</td>
<td>10</td>
<td>83.3</td>
</tr>
<tr>
<td>B</td>
<td>1</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>16.6</td>
</tr>
<tr>
<td>Filter Brand</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Etymotic Research</td>
<td>6</td>
<td>10</td>
<td>6</td>
<td>12</td>
<td>81.0</td>
</tr>
<tr>
<td>ACS pro</td>
<td>4</td>
<td>1</td>
<td>3</td>
<td>0</td>
<td>19.0</td>
</tr>
<tr>
<td>Filter</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mild (9-10 dB)</td>
<td>4</td>
<td>3</td>
<td>4</td>
<td>6</td>
<td>40.5</td>
</tr>
<tr>
<td>Moderate (15-17 dB)</td>
<td>5</td>
<td>6</td>
<td>5</td>
<td>6</td>
<td>52.4</td>
</tr>
<tr>
<td>Strong (≥20 dB)</td>
<td>1</td>
<td>2</td>
<td>0</td>
<td>0</td>
<td>7.1</td>
</tr>
<tr>
<td>Management feature</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Yes</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>3</td>
<td>9.5</td>
</tr>
<tr>
<td>No</td>
<td>10</td>
<td>11</td>
<td>8</td>
<td>9</td>
<td>90.5</td>
</tr>
<tr>
<td>Cosmetic Feature</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Yes</td>
<td>6</td>
<td>3</td>
<td>5</td>
<td>2</td>
<td>38.1</td>
</tr>
<tr>
<td>No</td>
<td>4</td>
<td>8</td>
<td>4</td>
<td>10</td>
<td>61.9</td>
</tr>
</tbody>
</table>

4.4.3 Follow-up questionnaire

Participants were asked in open-item questions which situations they perceived the greatest benefit from, and difficulty with, the MHP. More than half reported a benefit in rehearsals (n = 23), and many while watching live music (n = 18) or when performing (n = 13). Conversely, difficult listening situations included performances (n = 12), solo practice (n = 6), group rehearsals (n = 5) and situations where conversation was necessary (n = 6). As shown in
Table 6, of the many benefits of MHP use reported by participants, the most often-reported was a noticeable reduction in tinnitus with use \((n = 19)\). Of the difficulties reported, many commented on over-attenuation, which at times led to the musician feeling disconnected, “it made sounds too soft and took away from the atmosphere and gig”. However, the most frequent difficulty associated with MHP use was insertion. To examine whether insertion difficulties were more likely to be reported by those who did not receive insertion training, we compared participants in the standard, person-centred and diagnostic conditions with those in the control condition. Using a Fishers Exact test, no significant difference was found between conditions, \(p = .68\).

Table 6. Reported benefits and difficulties with use of the hearing protectors.

<table>
<thead>
<tr>
<th>Benefits</th>
<th>n</th>
<th>Difficulties</th>
<th>n</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reduced/less tinnitus</td>
<td>19</td>
<td>None</td>
<td>11</td>
</tr>
<tr>
<td>Reduced listening fatigue</td>
<td>10</td>
<td>Insertion</td>
<td>10</td>
</tr>
<tr>
<td>Improved sound</td>
<td>9</td>
<td>Over attenuation</td>
<td>7</td>
</tr>
<tr>
<td>Listening comfort</td>
<td>9</td>
<td>Acclimatisation</td>
<td>6</td>
</tr>
<tr>
<td>Less worry</td>
<td>4</td>
<td>Comfort</td>
<td>4</td>
</tr>
<tr>
<td>Physical comfort</td>
<td>2</td>
<td>Occlusion</td>
<td>3</td>
</tr>
<tr>
<td>Reduced injury symptoms</td>
<td>2</td>
<td>Blending</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Loss of sound detail</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Under attenuation</td>
<td>1</td>
</tr>
</tbody>
</table>

4.4.4 MOSI

The MOSI goals for the 12 musicians in the person-centred condition were analysed. The number of personal goals created ranged from two to five per participant, with a total of 43. Each goal was then coded into one of 10 categories depending on the main aim of the goal expressed by the participant. The most popular goal for musicians \((n = 11)\) was the ability to
hear their own instrument/music clearly, e.g., ‘to be able to use [the earplugs] when playing and still hear the music.’ This was followed by goals related to blending in with other instrumentalists \((n = 8)\) and having the music evenly attenuated across the audible spectrum \((n = 5)\), e.g., ‘to have flat attenuation of sound.’ Other common goals addressed the desire for hearing to be protected \((n = 6)\), and reduction in tinnitus \((n = 5)\), dullness \((n = 4)\), and pain and discomfort \((n = 4)\). At follow-up each participant scored whether their goals had been achieved using the following scale; \textit{not at all} \((0)\); \textit{partially} \((1)\); \textit{mostly} \((2)\); \textit{completely} \((3)\) and \textit{exceeded} \((4)\). Of the 43 goals, six were unable to be scored as the participant had not yet had an opportunity to test them. Of the 37 completed goals, the scores ranged from 0 – 4, with a mean of 2.8. Twenty-nine goals \((78\%)\) were scored a 3 or 4, indicating that in general goals were well met with the earplugs.

### 4.4.5 Satisfaction

Using a 5-point Likert scale, 36 musicians reported their MHP were \textit{very useful}, five \textit{somewhat useful} and only one individual found them \textit{not very useful}. Participants were then queried further about their satisfaction with the earplugs, and their responses are displayed by condition in Figure 1. Overall, the majority reported being very \textit{satisfied} \((n = 33)\) or \textit{somewhat satisfied} \((n = 7)\), with two \textit{neither} or \textit{somewhat dissatisfied} with their earplugs. Satisfaction with the sound quality specifically was high across conditions, with 23 \textit{very satisfied}, 17 \textit{somewhat satisfied} and the remaining two either \textit{somewhat} or \textit{very dissatisfied}. Investigating participants’ satisfaction with the fit of the hearing protectors revealed most were either \textit{very satisfied} \((n = 30)\) or \textit{somewhat satisfied} \((n = 10)\), with two \textit{neither} or \textit{somewhat dissatisfied}.

During the exit questionnaire, participants were also asked to rate their satisfaction with their appointments. Results indicated high satisfaction across all four treatment conditions,
with 41 very satisfied and only one individual somewhat satisfied. Regarding the information provided, 40 were very satisfied and the rest somewhat satisfied (n = 2). When musicians were asked what they felt was useful from their appointments, hearing tests were nominated by 17 of the 32 tested, with three reporting it helped them feel ‘reassured’ about the state of their hearing. For the subject pool as a whole, hearing education (n = 15) and information on hearing protectors (n = 7) were next most frequently mentioned. One participant also commented on the results of their MHP verification, “[regarding] the test comparison between using the earplugs and not, I was surprised at the uniform results.” All participants indicated that they would recommend hearing protectors to a friend.

Figure 1. Participant satisfaction with various aspects of the hearing protectors.

Xa. Satisfaction with the earplug sound quality

Xb. Overall satisfaction with the earplug

Xc. Satisfaction with the earplug fit

Xd. Perceived usefulness of the earplug
4.5 DISCUSSION

In this study, we aimed to explore whether satisfaction with, and usage of, MHP could be affected by the protocol used by the treating audiologists. Given the positive impact that person-centred approaches have had globally in improving health-care outcomes, this study sought to specifically investigate if the adoption of person-centred approaches, as represented by the diagnostic and person-centred conditions, would also show improved satisfaction with MHP by end-users. To this end, all participants were questioned as to their satisfaction at the conclusion of the study. However, overall, most subjects reported being satisfied and very satisfied with all aspects of the MHP. For example, 97.6% were very satisfied with their appointments and 95.2% reported as being either satisfied or very satisfied with the quality of their MHP, and hence no significant difference could be found in ratings across conditions. A limitation on this finding is the relatively small sample size overall and within each treatment condition, and further studies with a larger sample would be necessary to fully explore differences between treatment conditions.

While between-treatment comparisons were not possible, open-ended responses did provide information as to which elements of the protocol were viewed favourably by musicians. The most positively viewed aspect of service delivery was the provision of a hearing test, mentioned by 52% of individuals tested. This is an important finding, as results reported in McGinnity et al., (2018), found pure-tone audiometry was not included in the protocol by most audiologists when seeing musicians for MHP. In that study, only 11 of the 31 audiologists surveyed conducted a hearing test, and fewer incorporated complementary diagnostic components such as tympanometry and speech testing (McGinnity et al. 2018). Regarding the difficulties MHP posed for users, the findings of the present study contrasted to previous results reported in the literature. For example, 23.8% of the study sample here reported insertion to be difficult, with the next most-mentioned difficulty being over-attenuation of sound (16.7%). In
contrast, previous studies with musicians have mainly reported difficulties with sound blending, spectral and timbral distortion, balance and inaudibility of one’s own instrument (Huttunen, Sivonen & Poykko, 2011; O’Brien et al. 2014). Furthermore, difficulties with the occlusion effect were low in our subjects, with only three of the 42 subjects mentioning this in their survey responses. Few complaints surrounding occlusion may have been the result of our use of long-length earplugs and open-mouth impressions, techniques previously shown to reduce the occlusion effect (Pirzanski, 2006). It is notable also that five of the six cases where earplug modifications were required, involved vocalists and/or brass/woodwind instrumentalists suggesting that problems with occlusion may have played a role.

A fitting appointment, which provided insertion training and fit-checking of the MHP, was a component in three of our treatment conditions. This has previously been shown to provide benefit, in particular surrounding earplug insertion (Toivonen et al. 2002; Tsukada & Sakakibara, 2008). One aspect previously unexplored in relation to MHP is how often post-fit alterations are required and whether they are beneficial. While not a direct aim of our study, a unique finding was that 14.3% of musicians did in fact require post-fit alterations to their MHP and many were identified as a by-product of the fitting process. Alterations included modifications to improve physical fit or comfort, to a change in the attenuation filter. Importantly, only one individual self-nominated for such modifications, having the awareness to both identify their need and advocate for it. The remaining five instances were clinician-identified during the fitting/follow-up components of the person-centred and diagnostic conditions. It was noted that none of the musicians from the control condition, who did not have access to fitting or follow-up contact, self-advocated for alterations. Considering each alteration was a likely step towards improved comfort or sound, it is logical to assume each may improve the uptake and usage of MHP by musicians, yet if left to the musicians to identify the need for alterations, it is likely that many will remain unnoticed.
Regarding hearing health, participants appeared cognisant of the risk to hearing in the music industry, with 92.9% self-identifying as being at risk. Despite this, 38.1% had rarely or never used MHP, and a further 35.7% believed ad-hoc materials, such as cotton-wool, were a viable form of protection against harmful sound levels. This mismatch aligns with previous research by Jamieson (2015) and Zander and colleagues (2008) whose studies on sound-industry workers and orchestral musicians, respectively, found that awareness of risk and of MHP did not always translate to healthy hearing behaviours. Tinnitus experienced on a frequent basis was reported by 16.7% of our subjects, falling within prevalence estimates spanning 7.4% to 29.3% of the general population (McCormack et al. 2014; Park et al. 2014; Gallus et al. 2015; Manche et al. 2016). However, tinnitus and hearing injury in general, were often experienced after a rehearsal or musical performance. In our subjects, hearing dullness, blocked ears and distortion were all reported, negative symptoms frequently associated with music over-exposure, yet tinnitus was the most common, experienced by 81% in the past after a work-shift (Kähäri et al. 2003). It is not surprising, therefore, that the most frequently reported benefit of MHP at follow-up was a noticeable reduction in tinnitus, noted by 42.5% of our study musicians. In addition, other positive benefits such as reduced listening fatigue and improvement in sound quality were reported. Beach and O’Brien (2017) found similar benefits, with 22 of their 23 musicians commenting on the hearing protection gained by using earplugs, as well as improved sound quality and comfort.

The MOSI revealed that for many musicians, the clarity of the sound of their own instrument and the instruments of others was a high priority. In 10 of 16 cases, this goal was scored a ‘3’ or ‘4’ when earplugs were fitted, indicating that clarity and good sound quality were attained or exceeded for most participants. Other goals that were mentioned by several participants included a desire for ‘flat’ sound attenuation and for hearing to be protected. Both goals reinforce the importance of including verification as part of MHP service delivery.
Verification provides an ideal opportunity for audiologists to demonstrate the ‘flatness’ that is achieved by the earplugs and gives the musician a tangible appreciation of the hearing protection that is being provided by MHP.

The current study is limited both by the relatively small sample size, as well as a ceiling effect of positive responses leading to a lack of variation across conditions, in particular, regarding the satisfaction reported by musicians with their MHP. In addition, the subject pool here was surprisingly homogenous in the genre of music played, being mostly pop and rock music, possibly contributing to the lack of variation observed. There is also the possibility that “clinician bias” affected the results, given that all three research clinicians providing treatments had a deep interest in the topic. Their personal knowledge may have meant that even the control condition presented a standard of care that was more tailored to musician’s needs than would have been provided by standard clinical practice. Musicians were also followed up for responses relatively soon after the fitting of their hearing protection, at a minimum of two-weeks. Future studies comparing different treatment conditions should be extended to larger subject groups and include longer periods of time before follow-up questionnaires on benefits. Despite these limitations, the results of the study confirm that MHP did provide valuable benefits for musicians and identified insights into how the care of musicians can be improved by including full assessments of hearing, the make of long-length canal moulds, and a fitting process to identify any necessary alterations to support success.
4.6 CONCLUSION

Overall, satisfaction with MHP across treatments was high, and no differences could be identified across conditions, including in support of person-centred approaches. Results of the study confirmed the benefits to musicians of MHP use, particularly in the reduction of tinnitus. The use of the MOSI provided an opportunity for musicians to state specific goals and for audiologists to tailor audiological care to meet those individual goals. Furthermore, the inclusion of verification and a hearing test in the process was positively received by musicians. Lastly, musicians rarely self-identified the necessary modifications to their earplugs that would support successful outcomes. These were more often clinician-identified in fit/follow-up appointments, supporting the inclusion of this component in the care of musicians regarding their prescribed hearing protectors.
REFERENCES


APPENDICES

Pre-appointment questionnaire

The following is a list of relevant and reported items from the questionnaire, some items have been excluded for brevity.

YOU AND YOUR HEARING

What is your gender?
( ) Female
( ) Male
( ) Indeterminate/intersex/unspecified

What is your date of birth?

Tinnitus is defined as any sound that a person can hear internally that is not present externally. It may be heard as a buzzing, ringing, whistling, hissing or pulsing sound. Have you ever experienced tinnitus?
( ) Never/almost never
( ) Occasionally
( ) Sometimes
( ) Frequently
( ) Always/almost always
( ) Unsure

[If present]
How would you rate the severity of your tinnitus?
( ) Mild
( ) Moderate
( ) Severe

Have you ever experienced the following or a worsening of the following after a performance or rehearsal? (select all that apply)
( ) Ringing in the ear (tinnitus)
( ) Hearing dullness
( ) Blocked sensation in the ears
( ) Pain in the ears
( ) Sound distortion
( ) Other (please describe):
( ) None of the above

YOUR WORK AND TRAINING

How would you describe your work in the music industry?
( ) Professional (full-time)
( ) Professional (part-time)
( ) Freelance
( ) Amateur/recreational
( ) Other (please describe):

What instrument(s) do you play?

What music genre(s) do you mostly play?

Have you completed or are you enrolled in any music-related training?
( ) Yes (please describe):
( ) No

On average, how many times do you perform each month?
( ) About once a month
( ) 1-5 times a month
( ) 5-10 times a month
( ) More than 10 times a month

Please describe the various roles you perform as a musician (i.e. performer, teacher, writer).

HEARING PROTECTION

Do you believe your hearing is at risk working as a musician?
( ) Yes
( ) No
( ) Unsure

Have you worn hearing protectors before?
( ) Yes
( ) No

[If yes]
Please describe why (select all that apply)
( ) I haven’t thought about it before
( ) I’m not at risk of hearing damage
( ) The risk of hearing damage is part of the job

( ) Earplugs are uncomfortable
( ) Earplugs prevent me from being able to do my job
( ) Earplugs are a hassle
( ) Earplugs are too noticeable
( ) Custom-made earplugs are too expensive
( ) Other (please describe):

How often would you wear hearing protectors?
( ) Never/almost never (less than 10% of the time)
( ) Occasionally (less than 50% of the time)
( ) Sometimes (around 50% of the time)
( ) Frequently (more than 50% of the time)
( ) Almost always/always (more than 90% of the time)

Have you always worn hearing protectors in music?
( ) Yes
( ) No

Why did you start to use hearing protectors?

What type of hearing protectors have you worn? (select all that apply)
( ) Tissue/cotton wool in the ear
( ) Foam earplugs
( ) Non-custom, filtered earplugs
( ) Custom-made earplugs
( ) Custom-made vented earplugs
( ) Custom-made electronic earplugs
( ) In-ear monitors
( ) Custom in-ear monitors
( ) Acoustic screens
( ) Other (please describe):
( ) None of the above

Please describe the situation(s) you have worn hearing protectors in (e.g. when performing).

Why do you choose, or would you choose, to wear hearing protectors? (select all that apply)
( ) To protect my ears from hearing loss
( ) To protect my ears from tinnitus
( ) I have hearing loss and I don’t want it to get worse
( ) I have tinnitus and I don’t want it to get worse
( ) To reduce the severity of my hearing-related symptoms after a shift (rehearsal/performance)
( ) My boss requires me to do so
( ) Other:

Before we leave you, your opinion is very important to us. Is there anything else you’d like to tell us?
Exit-interview questionnaire

The following is a list of relevant and reported items from the questionnaire, some items have been excluded for brevity.

HEARING PROTECTION USE

How useful did you find your hearing protectors overall?
( ) Very useful
( ) Somewhat useful
( ) Not very useful
( ) Not at all useful

In which situation(s) did you find your hearing protectors most useful?

In which situation(s) did you find your hearing protectors least useful?

Did you experience any difficulties with the use of your hearing protectors (i.e. discomfort, made sounds too soft etc.)?

Did you experience any benefits to the use of your hearing protectors (i.e. experienced less tinnitus after a show)?

Did you require any modifications to your hearing protectors (i.e. change in filter or mould)?

How satisfied are you with the fit of your hearing protectors (i.e. comfort, retention etc.)?
( ) Very satisfied
( ) Somewhat satisfied
( ) Neither satisfied nor dissatisfied
( ) Somewhat dissatisfied
( ) Very dissatisfied

How satisfied are you with the sound quality of your hearing protectors (i.e. ability to hear your instrument, blend with others etc.)?
( ) Very satisfied
( ) Somewhat satisfied
( ) Neither satisfied nor dissatisfied
( ) Somewhat dissatisfied
( ) Very dissatisfied

How satisfied are you with your hearing protectors overall?
( ) Very satisfied
( ) Somewhat satisfied
( ) Neither satisfied nor dissatisfied
( ) Somewhat dissatisfied
( ) Very dissatisfied
CHAPTER 4 RESULTS

SERVICE DELIVERY

How satisfied were you with your hearing appointments?
( ) Very satisfied
( ) Somewhat satisfied
( ) Neither satisfied nor dissatisfied
( ) Somewhat dissatisfied
( ) Very dissatisfied

Did you feel you received adequate information on your hearing and music exposure to inform your decision on hearing protectors?
( ) Very satisfied
( ) Somewhat satisfied
( ) Neither satisfied nor dissatisfied
( ) Somewhat dissatisfied
( ) Very dissatisfied

Out of the hearing appointments, what did you find most useful?

Was there anything you believe could have been done better?

Would you recommend the use of hearing protectors to a colleague or friend?
( ) Yes
( ) No
( ) Unsure

In general, what do you think could be done to help protect the hearing of musicians in the music industry?

Before we leave you, your opinion is very important to us. Is there anything else you’d like to tell us?
Music is like a dream…

one that I cannot hear.

— Ludwig van Beethoven
CHAPTER 5

RISK OF HEARING INJURY IN LIVE-MUSIC SOUND ENGINEERS

The following paper is incorporated in its entirety in this chapter, inserted as submitted, with the exception of formatting changes to headings, tables, figures and references to maintain consistency throughout the thesis:

Manuscript under review


Aim: to assess the hearing of live music sound engineers and their risk of hearing injury.
5.1 ABSTRACT

Most studies of hearing loss prevention in the music industry focus on the risk of hearing injury to musicians. However, live-music sound engineers (LMSE) may also be at risk of hearing injury due to their work-related sound exposure. We studied 27 LMSE, all of whom underwent otologic examination, including audiometry, distortion product otoacoustic emissions (DPOAE), speech discrimination and uncomfortable loudness levels, and completed a questionnaire investigating their history of sound exposure and use of hearing protectors. Hearing thresholds were significantly poorer than normative data across multiple frequencies, and a significant proportion reported constant tinnitus (29.6%) and reduced sound tolerance (40.7%). Use of hearing protection was relatively low, with many reporting interference with their job when using them. Our results suggest LMSE are at risk of hearing injury due to their work-related sound exposure.
5.2 INTRODUCTION

The risk of hearing injury in the music industry has been reported previously in the literature, including studies of the impacts of excessive sound exposure on patrons, venue staff, and musicians (Patel, 2008; Beach, Williams & Gilliver, 2013; Szibor et al., 2018). However, most studies have focused on the risk to musicians, and only a handful of studies worldwide have investigated the hearing health of sound engineers. Live-music sound engineers (LMSE) act as quality control for the transfer of sound from artist to audience, manipulating the musical balance to suit a range of variables, from room acoustics to audience size. They are vital to the experience of live music and in many cases, play a critical role in managing the sound exposure of patrons and other staff. Obviously, like musicians, they rely heavily on their hearing for their occupation, and any threat of hearing injury poses, not only a health-related risk, but also the additional risk of impacting on their professional work.

Worldwide, roughly 16% of adult-onset hearing loss is attributed to damage resulting from exposure to occupational noise, making it second only to presbycusis as the leading cause of deafness in this cohort (Nelson, et al., 2005; Yamasoba et al., 2013). For LMSE, the occupational hazard to their hearing arises directly from the music that they help to create, and thus the appropriate nomenclature is music-induced hearing injury (MIHI). This encompasses a cluster of symptoms and auditory damage profiles, resulting from exposure to excessive and/or prolonged sound pressure levels). In acute forms, MIHI occurs as instantaneous metabolic destruction of the vulnerable inner-ear structures following exposure to sound above 130 dB HL. More common chronic forms, however, are acquired from cumulative metabolic injury due to exposure to moderate-to-loud sound levels over a prolonged period or from multiple incidents (Kujawa & Liberman, 2006; Wada et al., 2017). The reported auditory symptoms of hearing injury may include
hearing loss, tinnitus, distortion, diplacusis and hyperacusis. Kähäri et al. (2003) reported that 74% of 139 rock/jazz musicians surveyed experience such symptoms.

Hearing loss has been reported in musicians across multiple music genres, shaped in the traditional noise-notch between 3 and 6 kHz and often asymmetrical depending on the proximity of the ear to the sound-source or instrument (Jansen et al., 2009; Halevi-Katz, Yaakob & Putter-Katz, 2015; Kähäri et al., 2016). In addition, findings have shown that the frequency output of the instrument, or surrounding music, may influence the area of injury. For example, percussionists of the Persian daf drum (which emits percussive bursts between 146 and 290 Hz) exhibit corresponding low-frequency hearing loss at 250 Hz (Emami, 2014). Results of distortion product otoacoustic emissions (DPOAE), which can be an indication of cochlear outer-hair cell function, suggest that rates of cochlear injury are 9.3 times higher in high-school students with a history of amplified music exposure, as compared to those with no history of exposure (da Silva et al., 2017). More relevant to the discussion of risks of live music venues, Szibor et al. (2018) reported that 41% of 104 tinnitus patients presenting with music as their trigger, labelled their onset as being related to exposure at live music concerts. Further, as many as half of 125 rock/pop musicians surveyed reported tinnitus after a performance (Pouryaghoub, Mehrdad & Pourhosein, 2017).

Hyperacusis, often co-morbid with tinnitus, can be described as a painful, fearful or unpleasant response to sounds tolerable to others (Aaze, McFerran & Moore, 2018). While there have been no specific studies of hyperacusis in LMSE, in a group of 241 classical musicians, 79% had self-reported issues that related to reduced sound tolerance (Jansen et al., 2009). El Dib and colleagues studied the hearing of 82 sound technicians (a broad group that includes individuals involved with microphone operation, sound mixing, and video editing), and reported that 36.6% experienced constant tinnitus, and
50% were found to have a high-frequency hearing loss (El Dib et al., 2008). The results of these studies suggest LMSE, due to their exposure to similar environments as musicians and other professionals working with sound technology, may be at risk of hearing injury.

While the potential for music to be played at high volume has existed since the first mass fanfares of trumpet- or horn-blowers, development of music amplifiers as well as technological improvements in speaker technology, have significantly increased the volume levels that can be experienced. Investigations of musicians’ sound exposure have reported levels in classical music environments to be between 81 and 90 dB LAeq, and between 94 to 115 dB LAeq in rock/pop venues (Kähäri et al., 2003; Pawlaczyk-Łuszczyńska et al., 2017). Bulla (2003), in a study of studio-recording engineers, reported typical average sound levels of 80 to 95 dBA, placing 42% of the subjects in the category of needing hearing conservation monitoring.

Under workplace health and safety legislation, managing the risk of hearing injury for staff employed in music venues in Australia falls within the same legislative parameters as workers in other industries. This legislation limits sound exposure of an employee to 85 dB LAeq for an 8-hour work day without the need for provision of hearing protection or other hearing conservation measures. The “safe” exposure time is halved for any doubling of sound level (e.g. 88 dBA for 4 hours; Worksafe Victoria, 2017). However, these legislative criteria are based on research into the effects of continuous industrial noise exposure, and their application in the musical environment can be problematic, due to the variability of sound level and frequency that is a characteristic of all music.
As with all workplace hazards, there is a hierarchy of practices that may be employed to reduce risk to staff, such as isolating the noise source, or limiting the exposure time of staff. The use of hearing protectors (HP) is the option of last resort and should only be employed when other preferred systemic alterations have been implemented (Morata & Meinke, 2016; Worksafe Victoria, 2017). In a live music setting, the use of HP is often regarded as the most viable option, and yet the two available studies of HP use by sound engineers show relatively low usage rates. El Dib and colleagues reported that 14.6% of their sample of 82 regularly wore HP, while Jamieson reported consistent use in only 11% of the 230 sound and music industry workers surveyed (Pawlaczyk-Łuszczyńska et al., 2010; Jamieson, 2015). More critically, 18% of this sample stated they would never wear HP, with the main reason being the impact of HP on their ability to perform their job (47.6%). This is of concern, since consistency of use has been directly linked to effectiveness of HP issued. For example, Arezes and Miguel reported that when worn for 90% of the time exposed, the effectiveness of a HP with a 30 dB nominal attenuation value is reduced to 10 dB (Arezes & Miguel, 2002).

Given the relatively high exposure levels that typically are reported to exist in the live music environment in which sound engineers work, and the reported low use of HP, it is reasonable to suggest that sound engineers are at relatively high risk of hearing injury. Therefore, the current study aimed to perform an in-depth investigation of hearing health of LMSE. Conducted in two parts, it combined a hearing questionnaire with the results of an extensive audiological examination. The research hypothesis was that LMSE would report higher rates of hearing injury symptoms than expected based on normative data. Furthermore, it was expected that the injury profile would be directly linked to self-reported sound-related exposure. Finally, use of hearing protection and attitudes associated with its use were explored to gain an understanding of usage in this population.
5.3 METHODS

This study was conducted under the ethical approval and oversight of the Royal Victorian Eye and Ear Hospital Human Research Ethics Committee (Project 14/1225H) and conformed to the requirements of the National Statement on Ethical Conduct in Human Research (NHMRC 2018; Australian Government, 2003).

5.3.1 Questionnaire

Participants were invited to complete an online questionnaire exploring their hearing health, use of HP and history of music-related sound exposure (SurveyGizmo, Boulder, CO). Any participants who reported a history of ear surgery, use of ototoxic medication, non-music noise exposure, severe ear infections or ear/head trauma were deemed ineligible to participate. Informed consent was obtained online prior to questionnaire participation. At completion, participants were invited to attend a hearing assessment at the University of Melbourne Audiology Clinic.

5.3.2 Audiometry

On attendance, written informed consent was obtained. All tests were conducted by the same qualified audiologist within a sound-proof booth. Otoscopy was performed first, and any wax obstruction removed via curette prior to testing. Tympanometry was performed, using an Interacoustics Titan to screen participants for any clinical indications of middle ear pathology. If results were positive, the participant was removed from the study and referred for medical management.
Pure-tone thresholds were assessed using an Interacoustics audiometer (Affinity 2.0). In accordance with the Australian standard, AS/NZS 1269.4:2005, the frequencies of 0.5, 1, 2, 3, 4, 6 and 8 kHz were tested, with stimuli presented through either TDH-39P on-ear headphones (Telephonics), or EAR-Tone insert earphones (sizes 3A & 3B) in cases in which collapsing canals were indicated (Standards Australia, 2004). In addition, extended high frequencies (9, 10, 11.25, 12.5, 14 and 16 kHz), were tested using Koss R/80 circum-aural headphones.

DPOAE measurements were undertaken using Interacoustics Titan (module DPOAE440) and Otometrics ear tips. The test stimuli levels (L₁ and L₂) were 65 and 55 dB SPL, and an f ratio (f₂/f₁) of 1.22 was maintained for each primary frequency (f₁ and f₂). The test frequencies, as calculated by 2f₂ – f₁, included 1, 1.5, 2, 3, 4 and 6 kHz and a signal-to-noise ratio for each was recorded (dB SPL). This signified the difference between the absolute DPOAE value and the noise-floor at the measured frequency in the test booth. Each frequency was also given a pass/fail response as determined by Interacoustics clinical protocol.

Uncomfortable loudness levels (ULL) were tested in the left and right ears separately at 0.5, 1, 2 and 4 kHz. Participants were provided with verbal instructions and an accompanying visual guide to the categories of loudness (Cox et al., 1997). Pure tones were presented for approximately 1000 msec at an initial volume of 50 dB HL, ascending rhythmically in 5 dB increments until the subject interpreted the signal as uncomfortably loud and requested cessation. This process was repeated, and the results averaged to create a final ULL value at each frequency.

Lastly, speech in noise recognition was assessed using the high-cue condition of the Listening in Spatialised Noise Sentences test (LiSNs), with stimuli presented through
Sennheiser H215 headphones (Cameron & Dillon, 2007). The technical specifications of presentation are described in Cameron, Glyde & Dillon (2011).

5.3.3 Recruitment

Invitations to participate were posted online in dedicated sound engineer forums, targeting individuals who specifically worked in live music. Invitations were also shared via local health and music peak bodies, and their associated social-media networks.

5.3.4 Participants

Thirty-seven LMSE completed the online hearing questionnaire, and of these, 34 went on to attend a hearing assessment. Of those tested, 7 were excluded: 4 for medical management, 1 with a history of ear surgery, 1 with significant non-music noise exposure, and 1 for failure to complete the full test battery. Of the remaining 27 participants, the mean age was 34.3 years ($SD = 9.2$), ranging from 21 to 56 years, with an average of 12.3 years working in the industry ($SD = 9.0$). Participation of males outweighed females, with 92.6% ($n = 25$) being male, consistent with current estimates of females working in the industry.

5.3.5 Data analysis

The Statistical Package for the Social Sciences (Version 25.0) software was used to analyse results (SPSS Inc., Chicago, IL, United States). Closed-item questionnaire responses were explored with descriptive statistics, while open-ended items were coded into subject categories and investigated using chi-square tests. A mixture of descriptive
statistics, independent and paired t-tests were used to explore the numerical and ordinal data from each individual’s hearing test results, with the $p$-value to reach significance set at .05.

5.4 RESULTS

5.4.1 Hearing questionnaire

Twenty of the LMSE held formal qualifications, ranging from an apprenticeship to a University degree relevant to their profession, and 2 had on the job training (see table 1). Of these 22, 17 reported hearing safety was a component of their education, whilst for 5 it was not. The details of this training however, were often reported as unstructured - ‘Lecturers gave us bits of advice along the way, but there was never an official class’. Freelance was the most common form of employment (70.4%, $n = 19$), followed by full-time ($n = 5$) and self-employed ($n = 1$). A further two individuals reported undertaking a mix of part-time, casual and/or freelance work. Most reported working between 26 and 40 hours ($n = 10$) or more than 40 hours/week ($n = 10$), with the remaining seven working less than 26 hours/week ($n = 7$). When asked to nominate the various roles they had performed as sound engineers, front of house (where the focus is on mixing the sound for the audience), was most common, followed by studio work (i.e. recording engineer), system engineering (where the engineer is responsible, at larger scale concerts, for installation, tuning and quality control of sound systems) and monitor mixing (where the engineer creates a mix for the artist to be able to hear themselves). The rock genre was the most common environment worked in ($n = 26$), followed by other contemporary genres such as pop ($n = 16$), punk ($n = 15$) and electronica ($n = 15$).
Table 1. Highest relevant qualification held by Live Music Sound Engineers

<table>
<thead>
<tr>
<th>Training</th>
<th>n = 27</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diploma</td>
<td>13</td>
<td>48.1</td>
</tr>
<tr>
<td>No formal training</td>
<td>5</td>
<td>18.5</td>
</tr>
<tr>
<td>Certificate</td>
<td>4</td>
<td>14.8</td>
</tr>
<tr>
<td>Degree</td>
<td>2</td>
<td>7.4</td>
</tr>
<tr>
<td>On-the-job</td>
<td>2</td>
<td>7.4</td>
</tr>
<tr>
<td>Apprenticeship</td>
<td>1</td>
<td>3.7</td>
</tr>
</tbody>
</table>

5.4.2 Hearing injury

Participants were asked if they had experienced any of a closed set of 5 identified symptoms of hearing injury in the past. Ten self-reported general hearing difficulties (37%), 13 felt they had difficulty following speech in background noise (48.1%) and 15 self-reported a reduced tolerance of loud sounds (55.6%). Several reported experiencing either a ‘blocked sensation’ in their ears \((n = 11, 40.7\%)\) or otalgia in the past \((n = 7, 25.9\%)\). Only one individual had not experienced a symptom of hearing injury after a work shift. Overall experience of tinnitus was high, with 8 reporting that they heard it frequently or always \((29.6\%)\), 16 intermittently \((59.3\%)\), and only 3 reporting no experience of tinnitus at all \((11.1\%)\). Of the subjects who reported experiencing tinnitus, on a 3-point scale from mild to severe, most rated the severity as mild \((n = 22, 91.7\%)\), however 2 indicated that their tinnitus was of moderate severity \((8.3\%)\).

Participants were then asked which hearing injury symptoms they had experienced specifically during or after a work shift as a sound engineer. As shown in Table 2, tinnitus was noted as being experienced by 81.5% in this scenario. In addition, other hearing injury symptoms such as dullness, blocked ears, otalgia and distortion were
also reported. Only one participant reported that they had not experienced a symptom of hearing injury during or after a work shift. However, it should be noted that this participant was found to have the most severe hearing loss of all participants in the study.

Table 2. Hearing injury symptoms previously experienced after a work shift.

<table>
<thead>
<tr>
<th>Symptom</th>
<th>n</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tinnitus</td>
<td>22</td>
<td>81.5</td>
</tr>
<tr>
<td>Dullness</td>
<td>14</td>
<td>51.9</td>
</tr>
<tr>
<td>Blocked Ears</td>
<td>6</td>
<td>22.2</td>
</tr>
<tr>
<td>Otalgia</td>
<td>4</td>
<td>14.8</td>
</tr>
<tr>
<td>Distortion</td>
<td>3</td>
<td>11.1</td>
</tr>
<tr>
<td>None</td>
<td>1</td>
<td>3.7</td>
</tr>
</tbody>
</table>

5.4.3 Hearing protection

A total of 26 of the 27 participants reported that they had worn HP during a work shift. However, usage was highly variable. Based on a definition of frequent use being >20% of work time versus infrequent use being <20% of work time, 14 of the sound engineers reported using HP frequently (51.9%), and 13 used them infrequently (48.1%). Of those that had worn HP, motivating factors for use included: risk reduction surrounding hearing damage and its associated consequences (n = 15) - “My ears are my money makers. Deaf equals broke!”; as well as previous experience of hearing injury symptoms, such as tinnitus (n = 8) or hearing loss (n = 8) - “I was scared of hearing loss after repeated and more frequent ringing in my ears”. The type of hearing protectors worn by the participants during a work shift is shown in table 3. Eighteen had been
supplied HP by an employer (type not specified). In addition, use of other preventative measures, such as hearing awareness training, was rare \((n = 2)\) and hearing tests \((n = 2)\) were not commonly used.

Table 3. Hearing protectors worn by live music sound engineers during a work shift

<table>
<thead>
<tr>
<th>Hearing protector</th>
<th>(n = 27)</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Foam</td>
<td>24</td>
<td>88.9</td>
</tr>
<tr>
<td>Non-custom, filtered</td>
<td>13</td>
<td>48.1</td>
</tr>
<tr>
<td>Custom</td>
<td>11</td>
<td>40.7</td>
</tr>
<tr>
<td>Tissue/cotton wool</td>
<td>6</td>
<td>22.2</td>
</tr>
<tr>
<td>Non-custom, in ear monitor</td>
<td>6</td>
<td>22.2</td>
</tr>
<tr>
<td>Custom, in ear monitor</td>
<td>4</td>
<td>14.8</td>
</tr>
<tr>
<td>Custom, vented</td>
<td>4</td>
<td>14.8</td>
</tr>
<tr>
<td>Electronic</td>
<td>0</td>
<td>-</td>
</tr>
<tr>
<td>Other</td>
<td>1</td>
<td>3.8</td>
</tr>
</tbody>
</table>

The situations in which sound engineers reported using HP highlight the importance placed on the quality of audition, with the majority choosing only to wear HP when there was less need for hearing acuity, e.g. “Generally, I will not wear plugs if I’m working for important artists or promoters because I need the extra detail to really nail the mix. If I start to feel fatigued, the plugs go straight in and stay in. If it is an unimportant show, the plugs are in the whole time.” Use of HP was also more common in environments with loud genres, “Mixing monitors, dance, rock, metal, I will always have plugs in my kit and
I evaluate when to use them on a gig by gig basis” or where hearing acuity was subjectively interpreted as less critical, “If I’m not doing FOH I always use earplugs”.

5.4.4 Hearing risk

Using a 3-point scale, participants were asked if they perceived their hearing to be at risk working in the music industry. Most (i.e. \( n = 20, 74.1\% \)), reported their hearing as very much at risk, 6 perceived a little risk to their hearing (22.2%), and only one thought their hearing was not at risk in the industry (3.7%). When asked who they believed was most at risk in the music industry, participants ranked musicians as most at risk, followed by sound engineers, venue staff, DJ’s and patrons. Regarding genre, metal \((n = 28)\), rock \((n = 22)\), electronica \((n = 19)\) and punk \((n = 18)\) were considered the genres that posed the highest risk for causing hearing injury, whilst country \((n = 14)\), folk and jazz \((n = 1)\) were viewed as relatively low risk. Interestingly, classical music was not perceived as a risk by any of the participants.

Participants were asked to identify who they felt was responsible for mitigating the risk of hearing injury in a live music venue. Sound engineers and venue management were ranked equally as being most responsible \((n = 23)\), followed by the performing artists \((n = 18)\), venue owners \((n = 15)\) and DJs \((n = 15)\). Participants were also asked to report on barriers preventing safe sound level management in music venues. The most commonly reported barrier was the perception that high sound levels were in fact desired by patrons \((n = 11)\) and/or by the performing artists \((n = 9)\); “The desires and beliefs of uneducated punters and musicians. That it’s sheer volume that provides a visceral musical experience”. Frustration with issues such as difficult room acoustics \((n = 8)\) and poor-quality sound equipment \((n = 8)\) were also mentioned, along with a lack of education of
both patrons ($n = 5$) and the operating sound engineer ($n = 5$). In discussing what might be helpful ways to better manage sound levels in live music, the provision of hearing protection ($n = 14$) came first, followed for the need for greater education and awareness of the public ($n = 10$) and improvement in acoustics and sound systems of rooms ($n = 6$).

Participants also commented on the conflicting expectations in their environment “What I struggle with, and that I’d like to see change, is the belief among musicians and punters that an exciting musical experience is dependent on being loud.” Some reported plans to transition out of live music to allow for career longevity, “I’m currently working as a live sound engineer, but I want to transition to the studio and sound design. One strong reason is the risk of hearing damage”, with many recognising the inherent link between their ears and profession, “Ultimately we get paid to hear things...If we can't hear then we can't work... Seems simple.”

5.4.5 Pure-tone audiometry

Paired samples $t$-tests were used to investigate the inter-aural differences of subjects at each pure-tone audiometry frequency. For most, a non-significant difference was observed between ears ($p > .05$), however, three frequencies reached significance with the left ear being poorer than the right ear. This was observed at 0.5 kHz ($t(26) = 3.4, p < .05$), 12.5 kHz ($t(26) = 2.3, p < .05$) and 14 kHz ($t(26) = 2.8, p < .05$). Taking this into account, the results for left and right ears were pooled instead of averaged, creating a database of 54 ears (see table 4). When thresholds were averaged in terms of low (0.25 ≤1kHz), high (2≤8 kHz) and extended high frequencies (9≤16 kHz), the percentage of ears exhibiting hearing loss, as defined by thresholds ≥25 $dB HL$, were 3.7% ($n = 2$), 7.4% ($n = 4$) and 18.5% ($n = 10$), respectively.
Table 4. Participant pure-tone hearing thresholds at each test frequency

<table>
<thead>
<tr>
<th>Frequency (Hz)</th>
<th>n = 54 ears</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>250</td>
<td>1</td>
<td>1.9</td>
</tr>
<tr>
<td>500</td>
<td>2</td>
<td>3.7</td>
</tr>
<tr>
<td>1000</td>
<td>2</td>
<td>3.7</td>
</tr>
<tr>
<td>2000</td>
<td>2</td>
<td>3.7</td>
</tr>
<tr>
<td>3000</td>
<td>4</td>
<td>7.4</td>
</tr>
<tr>
<td>4000</td>
<td>5</td>
<td>9.3</td>
</tr>
<tr>
<td>6000</td>
<td>4</td>
<td>7.4</td>
</tr>
<tr>
<td>8000</td>
<td>5</td>
<td>9.3</td>
</tr>
<tr>
<td>9000</td>
<td>8</td>
<td>14.8</td>
</tr>
<tr>
<td>10 000</td>
<td>9</td>
<td>16.7</td>
</tr>
<tr>
<td>11 250</td>
<td>10</td>
<td>18.5</td>
</tr>
<tr>
<td>12 500</td>
<td>12</td>
<td>22.2</td>
</tr>
<tr>
<td>14 000</td>
<td>15</td>
<td>27.8</td>
</tr>
<tr>
<td>16 000</td>
<td>29</td>
<td>53.7</td>
</tr>
</tbody>
</table>

Hearing thresholds of the LMSE were then compared to normative data, referencing ISO 7029:2017 for frequencies $0.25 \text{ kHz} \leq 8 \text{ kHz}$, using the equation $H = \alpha (Y–18)\beta$, in which $H$ denotes hearing threshold (dB HL), $Y$ indicates age and the gender specific coefficients for frequency represented by $\alpha$ and $\beta$. For frequencies $9 \text{ kHz} \leq 16 \text{ kHz}$, normative data was sourced from Jilek et al., so that subjects below the ISO 7029 cut-off of 22 years could be included. Equation $H = \alpha (Y–18)^2$ was used for 9, 10 and 11.25 kHz, and $H = \beta$ for the frequencies of 12.5, 14 and 16 kHz, enlisting gender appropriate $\alpha$ and $\beta$ values.

The results of paired samples t-tests showed that the hearing thresholds of LMSE were significantly poorer than expected at all standard audiology frequencies ($0.25 \text{ kHz}$
≤ 8 kHz, \( p < .05 \), with the greatest mean difference, 8.7 dB HL, observed at 4 kHz (\( M_{\text{LMSE}} = 11.9, SD = 12.6; M_{\text{ISO norms}} = 3.2, SD = 4.0 \)), \( t(53) = 6.6, p < .05 \). The opposite was seen at 14 kHz, however, with LMSE showing significantly better hearing than normative data (\( M_{\text{LMSE}} = 14.8, SD = 22.1; M_{\text{ISO norms}} = 23.0, SD = 19.0 \)), \( t(53) = -3.8, p < .05 \) (see figure 1).

Figure 1. The mean hearing threshold of Sound Engineers \((n = 54\) ears\) compared to corresponding normative data, referencing ISO7029:2017 for frequencies 0.25 kHz ≤ 8 kHz, and Jilek et al. for 9 kHz ≤ 16 kHz.\(^{29,30}\) Denotes thresholds with a significant difference between groups, \( p < .05 \).

Independent \( t \)-tests were performed to investigate within group differences, segregating the LMSE as defined by their use of HP (frequent vs infrequent). As can be seen in figure 2, hearing thresholds at all test frequencies appeared better in subjects who wore HP frequently (i.e. more than 20% of their work-time). This difference however, reached statistical significance in only the following frequencies; 3 kHz (\( M_{\text{freq}} = 6.6, SD_{\text{freq}} = 8.8; \)
\[ M_{\text{infreq}} = 12.3, \ SD_{\text{infreq}} = 11.3; t(52) = 2.1, p < .05 \] in the high-frequency range, and 11.25 kHz \((M_{\text{freq}} = 7.5, SD_{\text{freq}} = 17.4; M_{\text{infreq}} = 19.4, SD_{\text{infreq}} = 22.3; t(52) = 2.2, p < .05)\), 12.5 kHz \((M_{\text{freq}} = 8.6, SD_{\text{freq}} = 17.5; M_{\text{infreq}} = 24.0, SD_{\text{infreq}} = 25.5; t(44) = 2.6, p < .05)\), 14 kHz \((M_{\text{freq}} = 5.7, SD_{\text{freq}} = 16.9; M_{\text{infreq}} = 24.6, SD_{\text{infreq}} = 23.1; t(52) = 3.5, p < .05)\), and 16 kHz \((M_{\text{freq}} = 16.6, SD_{\text{freq}} = 20.6; M_{\text{infreq}} = 30.2, SD_{\text{infreq}} = 17.2; t(52) = 2.6, p < .05)\), of the EHF’s. The greatest mean difference was observed at 14 kHz, of 18.9 dB.

Figure 2. Mean hearing thresholds comparing infrequent and frequent users of hearing protectors. * Denotes thresholds with a significant difference between groups, \( p < .05 \).
5.4.6 Distortion product otoacoustic emissions

Paired-samples *t*-tests comparing the signal-to-noise ratio (SNR) value of each DPOAE between left and right ears of participants was non-significant at all test frequencies (*p* > .05). Results were again pooled creating a 54-ear database and analysed for between group differences based on HP use. Independent *t*-tests comparing DPOAE SNR for each frequency found a non-significant difference between groups (frequent vs infrequent HP users) at all lower frequencies of 1, 1.5 and 2 kHz, *p* > .05. However, a significant difference was observed at all high frequencies, with frequent HP users (*M* = 19.8, *SD* = 5.5) having greater SNR than infrequent users (*M* = 15.0, *SD* = 7.7; *t*(52) = -2.7, *p* < .05) at 3 kHz, as well as at 4 kHz, with a higher SNR in frequent users (*M* = 21.2, *SD* = 7.2) than infrequent users (*M* = 15.4, *SD* = 11.1; *t*(52) = -2.3, *p* < .05), and at 6 kHz, comparing frequent users (*M* = 19.6, *SD* = 9.4) and infrequent users of HP (*M* = 13.9, *SD* = 9.6; *t*(52) = -2.2, *p* < .05).

The DPOAE responses for each ear were pooled to create a database of 54 ears and analysed. The results were first labelled as either clinically present or absent using the standard Titan Interacoustics protocol. In general, infrequent users of HP were more likely to display clinically absent DPOAE’s than those who used HP more frequently (see table 5).

5.4.7 Uncomfortable loudness levels

Responses of the LMSE to ULLs ranged from a minimum of 70 dB HL to a maximum of 120 dB HL, the upper limit of our audiometer, with average values displayed in table 6. The classification of ULLs were modelled from findings by Sherlock and Formby.\(^{31}\) Values < 95 dB HL at .5, 1 and 2 kHz were considered abnormally low, as
were those < 90 dB HL at 4 kHz. Conversely, results ≥ 95 dB HL at .5, 1 and 2 kHz, or 90 dB HL at 4 kHz, were considered normal sound tolerance. According to this classification, 11 of participants had abnormally low sound tolerance in at least one frequency of at least one ear (40.7%). Furthermore, 7 experienced abnormal sound tolerance in more than one frequency (25.9%), and 3 at all tested frequencies (11.1%).

Table 5. Percentage of absent distortion product otoacoustic emissions in the ears of sound engineers who frequent or infrequently used hearing protectors.

<table>
<thead>
<tr>
<th>Frequency (Hz)</th>
<th>Infrequent n (26)</th>
<th>%</th>
<th>Frequent n (28)</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>1000</td>
<td>2</td>
<td>7.7</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>1500</td>
<td>2</td>
<td>7.7</td>
<td>1</td>
<td>3.6</td>
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<tr>
<td>2000</td>
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<td>2</td>
<td>7.1</td>
</tr>
<tr>
<td>3000</td>
<td>4</td>
<td>15.4</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>4000</td>
<td>4</td>
<td>15.4</td>
<td>4</td>
<td>3.6</td>
</tr>
<tr>
<td>6000</td>
<td>7</td>
<td>26.9</td>
<td>3</td>
<td>10.7</td>
</tr>
</tbody>
</table>

Table 6. Mean uncomfortable loudness levels of live music sound engineers.

<table>
<thead>
<tr>
<th>Frequency (Hz)</th>
<th>Mean (dB HL)</th>
<th>SD</th>
<th>Min (dB HL)</th>
</tr>
</thead>
<tbody>
<tr>
<td>500</td>
<td>100.7</td>
<td>8.4</td>
<td>82.5</td>
</tr>
<tr>
<td>1000</td>
<td>102.0</td>
<td>9.2</td>
<td>82.5</td>
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<td>2000</td>
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<td>8.4</td>
<td>75.0</td>
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<tr>
<td>4000</td>
<td>94.1</td>
<td>11.0</td>
<td>70.0</td>
</tr>
</tbody>
</table>

Results of the ULLs in our sample were then pooled for comparison against normative data. Paired samples t-test revealed significantly reduced sound tolerance in LMSE (\(M = 99.0, SD = 8.4\)) compared to norms (\(M = 101.6, SD = 0.0\)), at 2 kHz, \(t(53) =\)
-2.34, \( p < .05 \). This finding was repeated at 4 kHz, with LMSE \( (M = 97.0, SD = 11.1) \) showing reduced tolerance of volume compared to norms \( (M = 100.8, SD = 0.0) \), \( t = -2.54, \( p < .05 \). No significant reduction in sound tolerance was seen in the LMSW ULL at .5 and 1 kHz. The results at each frequency are plotted against those expected by normative data in figure 3.

Figure 3. Uncomfortable loudness levels of live music sound engineers \( (n = 54 \) ears) against normative data \( (n = 59) \).\(^{31}\) * Denotes thresholds with a significant difference between groups, \( p < .05 \).

Using independent t-tests, no significant difference in ULLS was found between groups as defined by their HP use (frequent vs infrequent) at any test frequencies, \( p > .05 \). Furthermore, there was no significant difference found when comparing LMSE as defined by their self-reported experience of sound tolerance (sensitive vs not sensitive) at all tested frequencies \( p > .05 \). There was however, a significant difference based on experience of tinnitus, when the sample was divided into two groups as shown in figure
4: those who had never experienced tinnitus (nil tinnitus; \(n = 6\)); and those who had (tinnitus; \(n = 48\)). Independent \(t\)-tests indicated significantly reduced sound tolerance at 1 kHz for those who had experienced tinnitus (\(M = 100.6, SD = 8.4\)), as compared to those who had not experienced tinnitus (\(M = 113.7, SD = 7.4; t(52) = -3.7, p < .05\)). This was also seen at 2 kHz between the tinnitus group (\(M = 98.1, SD = 7.6\)) and nil tinnitus group (\(M = 105.8, SD = 11.6\)), \(t(52) = -2.2, p < .05\), and finally at 4 kHz between the tinnitus group (\(M = 95.9, SD = 11.1\)) and nil tinnitus group (\(M = 105.4, SD = 7.8\)), \(t(52) = -2.0, p < .05\). At .5 kHz Levene’s test indicated unequal variances (\(F = 5.2, p < .05\)), and degrees of freedom were adjusted from 52 to 23.7. Results, however, were significantly reduced in the tinnitus group (\(M = 99.6, SD = 8.2\)) when compared to those who had never experienced tinnitus (\(M = 109.6, SD = 2.5; t(23.7) = -6.4, p < .05\)).

Figure 4. Comparison of uncomfortable loudness levels between live music sound engineers who had or had not experienced tinnitus. * Denotes thresholds with a significant difference between groups, \(p < .05\).
5.4.8 Speech discrimination

Results of the high-cue LiSNs test were recorded as a SNR, with more negative results indicating better ability to follow speech in the presence of background noise, whereas more positive results indicate greater difficulty. The mean SNR for our sample was -18.2 dB (SD = 3.0), ranging from -8.4 ≤ -22.9 dB. Independent samples t-test revealed a non-significant difference between frequent (M = -18.1, SD = 2.4) and infrequent users of HP (M = -18.2, SD = 3.7) in their ability to discriminate speech in the presence of noise, t(25) = -.05, p = .96. Comparing subjects who self-reported hearing difficulties in background noise (M = -17.6, SD = 3.7), to those who did not (M = -18.7, SD = 2.2), a slight improvement in SNR was seen in ‘no difficulty’ respondents, however, this too did not reach significance, t(25) = .98, p = .33. A significant positive correlation was, however, observed between LiSNs performance and age, r = .53, with poorer discrimination as age increased, p < .05.

In relation to the test battery, LiSNs results were significantly correlated to DPOAE and PTA results. A negative relationship was seen between LiSNs and DPOAE results of the left ear at 3 kHz (r = -.49), 4 kHz (r = -.69) and 6 kHz (r = -.41) and of the right ear at 4 kHz, r = -.44, p < .05, such that as health of the OHCs of the cochlea worsened, so too did an individual’s ability to discriminate speech in noise. A positive correlation was also observed between all but three PTA frequencies (excluding left 16 kHz, and right 2 and 16 kHz) and LiSNs performance, with better speech discrimination in noise results shown in subjects with better hearing thresholds at most tested frequencies, p < .05.
5.5 DISCUSSION

The aim of this study was to investigate the hearing health of sound engineers who work specifically in live music. Our hypothesis was that LMSE would show signs of hearing injury related to their occupation. Subjective results from the study support the hypothesis, with 74.1% of participants reporting that their hearing was very much at risk in the industry. Self-reported symptoms of MIHI were also high, with 37% of subjects self-reporting hearing difficulty and 48.1% reporting difficulty following conversation in background noise. Notably, symptoms of temporary threshold shift were high, with 51.9% reporting having experienced hearing dullness and 81.5% reporting tinnitus during or after work. This is an important finding when considering that animal studies have demonstrated permanent and ongoing injury may occur after each high-intensity insult, as well as accelerate the progression of age-related hearing loss later in life (Kujawa & Liberman, 2006). However, this result has yet to be explored in human studies and must be integrated accordingly. Here we found that 96.3% of participants had experienced at least one sign of hearing injury connected to their sound exposure, which suggests the need for greater awareness of the risks of hearing injury in this profession, and more concerted efforts to reduce these risks.

Previous studies in animal models have shown that with exposure to high sound levels, deafferentation of auditory nerve fibres occurs both immediately and later, driving a reduction of peripheral input to the auditory cortex (Kujawa & Liberman, 2009; Norena & Eggermont, 2015). In response, the spontaneous firing rate of central mechanisms are increased to maintain homeostasis of the system (Kaltenbach, 2006; Bauer, Brozoski & Myers, 2007; Eggermont & Kral, 2016). In theory, the unfortunate side-effect of this central gain is the genesis, in part, of both tinnitus and hyperacusis which often occur in the presence of one another (Gu et al., 2010; Knipper et al., 2013; Aazh et al., 2018).
Considering the substantial history of sound exposure in our cohort, it is not surprising that 29.6% reported experiencing constant tinnitus and 55.6% self-reported issues with volume. Further, 40.5% of the sample met the criteria for reduced sound tolerance, which when compared to normative data, were significantly lower for both 2 and 4 kHz. More importantly, those who reported experiencing tinnitus were found to have reduced tolerance across all tested frequencies as compared with those not reporting tinnitus. Taken together, these results show that sound engineers in our study were more likely to report sound as uncomfortable at lower sound levels than the average individual, an interesting finding because it suggests that many LMSE are likely exposed to music above levels they regard as comfortable.

Measurable deterioration in hearing thresholds in our participants was not prevalent for either low or high frequencies (3.7% and 7.4% respectively), however 18.5% had measurable hearing loss in the extended high frequencies (between 9 and 16 kHz). This frequency region is of importance from a conservation perspective, considering reports that these frequencies are more vulnerable than conventional audiometric frequencies to the impacts of significant sound exposure and should be monitored for at-risk individuals (Mehrparvar et al., 2014; Ma et al., 2018). When LMSE were divided into two groups based on their use of HP, we found that those who reported wearing HP more frequently showed better hearing thresholds at all tested frequencies as compared to those reporting infrequent HP use. This result reached statistical significance at five key frequencies, firstly at 3 kHz, a frequency central to the traditional noise-notch pattern of those over-exposed to sound, and secondly, at all EHF between 11.25 and 16 kHz. 4,9,10 Here the mean difference between frequent and infrequent users was particularly evident at 14 kHz, with frequent users of HP demonstrating better hearing thresholds by a mean of 18.9 dB than infrequent users. Finally, this finding was further supported by DPOAE
results, with LMSE reporting frequent HP use having significantly better results at 3, 4 and 6 kHz. Together, these results support the inclusion of EHF testing in any program involving the conservation LMSE’s hearing.

Many participants commented that the use of HP interfered with their work, be it by reducing sound levels (i.e. 100 dB sounds very different to 85 dB) or adding spectral distortion. Furthermore, the most commonly reported reason for infrequent HP use cited by our LMSE was the impact that HPs have on their ability to do their job, which relies strongly on quality of audition. These complaints are consistent with findings that use of HP introduces spectral imbalances to the musical signal (Chesky & Amlani, 2015). It may be that encouraging individuals to use HP whenever audition is non-critical, as opposed to the all-or-nothing approach often advocated in industrial steady-state noise environments, may lead to higher rate of uptake amongst sound engineers. Although further investigation is needed, our finding that even those who wore HP at least 20% of the time demonstrated significantly better hearing than less frequent wearers suggests that intermittent HP may be an appropriate strategy in fluctuating live music environments.

When compared to normative data, LMSE displayed poorer hearing thresholds for all frequencies in the standard audiometry range (0.25 ≤ 8 kHz), with the worst affected being the central noise-notch frequency of 4 kHz. While the mean hearing threshold at this pitch by no means denotes hearing loss (11.9 dB HL), the fact that LMSE displayed poorer hearing by 8.7 dB HL than normative data could hint to early impact of their music-related sound exposure. Furthermore, the spread of impact appears to have extended beyond of the expected ‘noise’ region of 3-6 kHz. An explanation for this low-to-mid spread may come from the spectral balance of the music most LMSE reported working in. Rock music concerts have previously been reported to emphasise the lower frequencies, being up to 20-30 dB SPL greater than mid-high frequencies (Dibble, 1995).
As cited previously, one comparative study of hearing injury in music is reported for performers of the Daf, a traditional Persian drum that emits percussive low frequencies (146 – 290 Hz) with peaks of up to 130 dB SPL. In this paper, 65% exhibited hearing loss at 250 Hz (> 25 dB HL), and all 18 subjects exhibited a noise-notch at 3 kHz (> 25 dB HL). Furthermore, these musicians also exhibited vestibular impairment, with impact on the low-frequency stimulated saccule evident, something unexplored in this paper (Emami, 2014). It is possible that the findings of our study are consistent with the hypothesis that the spectral content of the surrounding noise exposure plays a role in the resulting area injury.

Sound engineers work in a unique situation, juggling the responsibility to faithfully transmit the sound that originates on stage, while managing the expectations of the audience and other stakeholders. Welch & Fremaux (2017) theorise expectations surrounding volume may derive from societal classical conditioning, pairing the long-standing experience of high sound levels in music with a positive reward. The reward may be anything from a feeling of social inclusion to enhanced emotional arousal (Welch & Fremaux, 2017). Of the sound engineers surveyed, many seemed cognisant of the cultural norms operating in venues, feeling a sense of pressure from both patrons and staff, to create sound levels beyond what they believed necessary or personally preferable;

“The most obvious solution is for sound engineers to mix quieter or create a frequency balance that is not fatiguing. For venues and promoters to be aware of damaging loudness levels and work with artists and engineers to keep it under control. However, the reality is many people have an expectation of loudness. There is a culture of loudness = better.”
Several also felt hearing conservation in the music industry was only possible with increased education and awareness, of both sound engineers, musicians and the public, acknowledging the low likelihood of reduced sound levels without a significant shift in its cultural acceptance. However, our findings noted that there was little coverage of hearing loss awareness in the training of most of our participants.

Due to the relatively small number of LMSE in our study (n=27), the statistical power of our analyses was limited and a study with a larger cohort would be of benefit to confirm our findings. Many questionnaire items relied on self-reporting by participants because of the subjective nature of many of the symptoms queried. This may have resulted in under or over representation of results. Although beyond the scope of this study, future analysis in this population would benefit from the inclusion of sound level measurements, including octave-band analyses in order to estimate individual noise exposures and gain a better understanding of the frequency components to which LMSE are exposed.

5.6 CONCLUSIONS

Live music sound engineers are an under-researched population who are potentially at high risk of injury to their hearing. More focused research and targeted education of this group is needed to help reduce their risk of hearing injury and to support career longevity. Use of hearing protection, even inconsistently, appears to have the potential to reduce risk. Furthermore, the results here support the inclusion of EHF testing in any conservation program involving this population. However, managing sound levels remains to be the most effective way to reduce risk for all who attend and work in live music venues. Before this can occur, cultural change and education of patrons, musicians
and venue management is needed if we are to challenge the belief that the quality of a musical performance is determined in kind by its volume.
REFERENCES


CHAPTER 5 RESULTS


CHAPTER 5 RESULTS


As music becomes less of a thing
- a cylinder,

a cassette,

a disc –

and more ephemeral,

perhaps we will begin to assign an increasing value to live performances again.

— David Byrne, How Music Works
CHAPTER 6

PREVENTING HEARING INJURY IN PATRONS AND STAFF OF LIVE MUSIC VENUES

The following paper is incorporated in its entirety in this chapter, inserted as submitted, with the exception of formatting changes to headings, tables, figures and references to maintain consistency throughout the thesis:

Manuscript accepted for publication


**Aim:** to investigate if the use of sound level management software can assist in reducing exposure levels in indoor live music venues.
6.1 ABSTRACT

Commercial software-based sound management systems have previously been used as an option to manage sound levels for large scale outdoor live music events. However, their use in indoor music venues, which represent a very different environment, has not been explored. We trialled use of a commercial audio sound level management system in six indoor live-music venues of Melbourne. Overall, there was no reduction in mean $L_{A_{eq,T}}$, however the number of nights on which extreme volume levels were recorded was reduced. Subjective questionnaires indicated that one-fifth of patrons would prefer lower sound levels than experienced.
6.2 INTRODUCTION

In contrast to the world-wide decline in recorded music sales, live music performances have seen a steady growth in attendance (IFPI, 2015). In the UK, it is estimated that live music contributes some £4.5 billion to the economy, whilst in Australia, there are an estimated 49 million attendances at live music events each year (Live Music Office, 2014; UK Music, 2018). As with any high sound level, exposure to music that is too loud, for too long a period, has the potential to cause damage to the auditory system, and may result in music-induced hearing injury (MIHI; Goggin et al., 2008; Carter, 2011; Tung & Chao, 2013). Symptoms may be temporary, for example transient tinnitus (i.e. a subjectively heard ringing in the ears), or a temporary threshold shift (i.e. reduction in hearing acuity for a brief period after an event). However, in some cases, symptoms may become permanent with additional exposure (Hellemen & Dreshler, 2015; Putter-Katz, Halevi-Katz & Yaakobi, 2015; di Stadio et al., 2018). It has been reported that as many as three in four professional musicians have at least one symptom of MIHI (Kähäri et al., 2003). Other studies suggest that regular patrons and staff within live music spaces are also at risk of acquiring MIHI (Gunderson, Moline & Catalano, 1997; Kelly et al., 2012; Bogoch, House & Kudla, 2005).

Acoustic measurements from music venues and concerts have regularly recorded sound levels in excess of 100 dB $L_{Aeq}$, with some events as high as 112 dB $L_{Aeq}$ (Clark, 1991; Guo & Gunn, 2005; Serra, 2005; Williams, Beach & Gilliver, 2010; Derebery et al., 2012). Under Australian workplace health and safety legislation, noise at work must not exceed the exposure standard of 85 dB $L_{Aeq,8h}$, with an exchange rate of 3 dB (Standards Australia, 2005). If this level is exceeded, the employer is required to take steps to reduce employees’ noise exposure. This might involve restricting access to the sound source or requiring that employees wear hearing protection devices. However,
translating these regulations to the music industry is complex, and adherence to them is sporadic at best. For instance, of the 17 music venues investigated by Guo & Gunn (2005) in Western Australia, 13 had not conducted any assessment of sound levels, 14 had not provided hearing loss prevention training to staff and use of hearing protection by staff was observed in only one venue. Similarly, Kelly et al., (2012) found that not one of the nine nightclubs examined in Ireland met regulations surrounding hearing conservation, even though the average daily exposure of employees was 92 dBA $L_{EX,8h}$, a finding echoed in Britain, where 70% of music venue employees were found to exceed their daily limit of noise exposure, with little use of hearing protection (Barlow & Castilla-Sanchez, 2012).

According to a recent report, there were 17.5 million annual patron visits at live music events in Melbourne during in 2017 (Newton & Coy-Hayward, 2017). According to the Live Music Office (2014), the most frequented locations for consumption of live music in Australia are small live-music venues. In interviews with representatives of 38 live-music venues around Australia, the report found that venues had a median capacity of 298 patrons and hosted a median of 18 performances per month (Live Music Office, 2014). According to an Australian database, recreational small-venue performances, colloquially known as gigs, regularly report levels between 86 and 102 dB $L_{Aeq,T}$, with a mean of 94 dB (Beach, Gilliver and Williams, 2013). At these sound levels, the workplace exposure standard is reached after only one hour. However, many patrons, and especially staff, are exposed to these sound levels for periods well in excess of an hour (Gunderson et al., 1997; Guo & Gunn, 2005; Kelly et al., 2012). Tracking the sound exposure of staff within a university entertainment precinct, Sadhra et al. (2002) reported the mean sound exposure of bar staff to be 90 dB $L_{Aeq}$ and 94 dB $L_{Aeq}$ for security members. Furthermore, temporary shifts in hearing of up to 50 dB HL were measured after sound exposure.
Similarly, sound levels to which patrons in music venues are often exposed to have been recorded above 95 dBA, and with mean exposure times of 5 hours, this places patrons at risk of hearing damage (Goggin et al., 2008).

To address the risks to hearing for staff and patrons, only a small number of countries have introduced legislation to guide management of sound levels at music events (Beach, Mulder & O’Brien, 2018). These approaches in general, rely on an averaged limit, whereby continuous equivalent sound levels (L_Aeq) over a set period, e.g. 60 minutes, must be below a certain limit, allowing for volume variation within a performance (Navne, 2015). However, studies have shown that upper sound level limits ranging between 99 and 103 dB L_Aeq over various periods of time are found across Europe (Tronstad & Gelderblom, 2016).

An interesting approach to addressing this issue is in the Flanders region of Belgium, where legislation was introduced in 2013 that classified music events into one of three ‘action’ categories. Category 1 includes events with sound levels up to 85 dB L_Aeq and at this level, no action is required. Category 2 includes events between 85 and 95 dB L_Aeq, at which monitoring from a valid reference point (typically front-of-house position), and the provision of visual feedback of sound levels to the responsible person(s), is required. Category 3 includes all events with sound levels above 95 dB L_Aeq. At these events, sound levels must be continually measured, visual feedback must be provided, and hearing protectors made available free to patrons. Furthermore, a maximum averaged output of 100 dB L_Aeq is enforced and all recordings are to be kept on file for 30 days. This tiered classification system imposes increasing compliance requirements as the sound level (and therefore the level of hearing risk) increases.

To assist music events in complying with the demands of these legislative requirements, a number of different sound level management systems have been
developed. These systems work by providing real-time sound level data that enable promoters, venue owners, management, and sound engineers to make informed decisions about sound levels at their event. In general, the systems, comprise a laptop and calibrated audio hardware to measure the A- and C-weighted sound levels of an event. Set to a time-averaged ‘target’, e.g. 98 dB $L_{A_{eq}} \text{ 15 min}$, sound levels are continually displayed through a visual interface, for example using a traffic-light display. Using this, the engineer is simultaneously presented with the sound levels in real time, along with an awareness of their dynamic ‘head-room’. The measurement is logged by the software and can be emailed to users for review at the end of the evening. In this way, the system maximises transparency, accountability and stakeholder engagement in the management of safe sound levels. While little research has been conducted to investigate its efficacy, its use in Flanders, for example, has seen a stabilisation in the sound levels of dance concerts to around 97-98 dB $L_{A_{eq}}$ during the period 2012-2014 (Kok, 2015).

Given the popularity in Australia of small live-music venues and the potential hearing risk associated with these venues, the authors were interested to see whether the use of sound level management software could have an impact on reducing the risk of MIHI for patrons and staff. The purpose of this study, therefore, was to investigate the influence of sound level management software on sound levels in a sample of Melbourne live-music venues. It was hypothesized that the use of a sound level management software system would lead to an overall reduction in sound levels in these small indoor venues, and that patrons would either not notice the change or perceive it favourably. A secondary aim was to investigate the perspectives of patrons and staff in relation to hearing health, experience of MIHI symptoms and use of hearing protection.
6.3 METHODS

This study was conducted under the approval and oversight of the Royal Victorian Eye & Ear Hospital’s Human Research Ethics Committee (project number 15/1225H). Informed consent was obtained from all participants. The study conformed to the requirements of the National Statement on Ethical Conduct in Human Research (NHMRC 2007, 2018).

6.3.1 Recruitment of venues

Seven small- to medium-sized live music venues within the Melbourne metropolitan area were sent an email inviting them to participate. Six agreed to do so and informed consent was obtained from the venue’s management or owner. No inducements or rewards were offered as compensation for participation, however, each venue was able to request a copy of the sound level results pertaining to their venue at completion. Employees and patrons within each venue were invited to participate in questionnaires either via email or in person, where appropriate. The number of staff and patrons who completed questionnaires at each venue are shown in table 1.

Table 1. Number of participating patron and staff within each venue.

<table>
<thead>
<tr>
<th>Venue</th>
<th>Capacity</th>
<th>Staff</th>
<th>Patrons</th>
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<tbody>
<tr>
<td>A</td>
<td>150</td>
<td>5</td>
<td>36</td>
</tr>
<tr>
<td>B</td>
<td>200</td>
<td>12</td>
<td>41</td>
</tr>
<tr>
<td>C</td>
<td>300</td>
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<td>E</td>
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<td>24</td>
<td>47</td>
</tr>
<tr>
<td>F</td>
<td>850</td>
<td>19</td>
<td>41</td>
</tr>
</tbody>
</table>

*Capacity refers to standing room*
6.3.2 Venues

As described following, the venues varied significantly on a range of features relevant to reverberation and noise levels. For example, in Venue A, the band room was located on the second floor of a heritage building, with various hard surfaces, wooden floors and minimal soft furnishings. Performances in this venue were regularly held very late in the evening, with harder styles, such as rock a common feature. Venue B was located in the city centre, partially below street level with a long, narrow band room, that incorporated a small dance floor, bar and patron lounge area. This venue was associated with a predominantly ‘grunge’ and ‘hard-core’ music scene. Venue C was also located centrally in Melbourne and featured several acoustic modifications on the walls and ceiling for increase sound absorption. The rectangular band room could be segmented into thirds, two parts a dance area, and one third a bar and seated patron area. Management of Venue D had recently undertaken upgrades of their sound-proofing and equipment. The band room was broad and devoted to patron viewing or dance, with only a small bar available to patrons in the corner of the room. The design of both venue C and D gave the impression that the attentive listening of the music was the intent of the band room, and performances in a variety of genres and band sizes were observed. Venue E was one of the largest in the study, with two band rooms within the venue, host to regular club nights as well as band performances. The band room included in this study was located on the ground floor with double-height ceilings and a mezzanine level from which patrons could observe performances. The bar was slightly removed from the line of sight of the stage. The final venue, F, was the largest in terms of capacity and in kind, hosted performances by more well-known, often international touring acts. The stage was elevated and there was a considerable distance from the front-of-house position to the stage. The bar was located at the back of the long, deep room, in line of sight of the stage.
6.3.3 Materials

Equipment. We employed a commercially available sound level management system which had previously been used by sound engineers and DJs in a range of applications and in research. Three systems were used, each one consisted of a laptop (Dell Inspiron, model P25T) with the proprietary software system installed (10EaZy version 2.6, SG Software, Denmark), a pre-amplifier and MK216 microphone (AS IEC 61672.1-2004). For each performance, three measures, $L_{A_{eq},1\text{min}}$, $L_{A_{eq},15\text{ min}}$ and $L_{A_{eq},60\text{min}}$, were recorded and stored on the laptop. On selected evenings, additional sound level measurements ($L_{A_{eq}}$ and $L_{C_{peak}}$) were recorded using five calibrated Casella dBadge (CEL-350) noise dosimeters. Finally, a run sheet was provided to operators so that set times for each performance could be recorded.

Maximum Average Manager (MAM). The system included a visual display referred to as a maximum average manager (MAM), which is projected for the sound engineer. This interface displays up to six red or green squares depending on the sound levels measured by the system (see figure 1). The mid-point in the display corresponds with the $L_{A_{eq},15\text{min}}$ target set by the user. The coloured squares are designed to convey to the sound engineer if they are over or under the target. For example, one red square indicates being 1 dB over target, while three green squares indicate being 3 dB under target. On closing, the system generates a summary report, which is emailed to selected individuals (e.g. venue owner, researcher), detailing the sound levels across the performance.
Figure 1. Sound level management system showing visual display in use front of house, used with permission from Kok (2015)

Hearing surveys. Two questionnaires were designed for the study: a demographic questionnaire for staff, and a sound level survey for patrons. Both were delivered via online platform, Survey Gizmo (SurveyGizmo, Boulder, Colorado). The demographic questionnaire covered employees’ hearing health, noise exposure at work, and use of hearing protection. The patron survey explored respondents’ satisfaction with sound levels, in addition to hearing health, live music attendance and use of hearing protectors.

6.3.4 Procedure

In each venue, the study was conducted in two parts, a baseline (control) condition, followed by the experimental condition. Prior to commencement of the control condition, the sound level management system was installed at the sound desk of the first of the six venues. The microphone was placed at approximate head height of the operator. It remained in this position for the duration of the study. During the control condition, the system recorded the A-weighted continuous equivalent sound level over 1-, 15- and 60-
minute periods at each live music performance held at the venue. The data were stored in a log file for subsequent review and analysis. During the control condition, the system was positioned such that the MAM was out of sight of the operator so as not to influence their behaviour.

On one occasion during the control condition, the sound levels measured by the system were corroborated using five dosimeters placed in fixed locations around the venue. The dosimeters were positioned at approximate head height in line with the main sound source on stage, at the sound desk, in the middle of the dance-floor, at the bar and the ticket desk. During this night, the questionnaires were administered. Patrons and staff were approached by a member of the roaming research team and invited to complete the survey on a tablet in between the performances of each band.

At the conclusion of the control condition, all data were compiled, and a brief report was prepared for each venue. The report detailed the venue’s sound level results (as measured by both the sound level management system and by dosimetry) and included information on the system with instructions on its use. Within this the MAM was described and the need for a LAeq,15min target to be set for the experimental condition. Each venue was requested to consider the results and select a target 15-minute sound level for their venue. Once chosen, the system was reinstalled at the venue, with the software set to the target nominated by the venue. On reinstallation, training was provided to the operating sound engineer by a member of the research team, who explained how to use the system. The experimental condition then commenced, and as in the control condition, measurements were logged at 1-, 15- and 60-minute intervals for each night of live music performance. Throughout the experimental condition, the visual display MAM of was made visible to the sound engineer so that they could track the sound levels in relation to the pre-set target.
On one occasion during the experimental condition, the additional dosimeter measurements were taken, and surveys were administered following the same procedures as in the control condition. This was completed between the live performance sets at each venue. At the completion of the experimental condition at the first venue, the same procedure was repeated in each of the remaining five venues. In each venue the control and experimental conditions occurred over a ten to sixteen-week period, and all six venues were completed within a period of 11 months.

6.3.5 Data analysis

Data analysis was conducted using version 25 of IBM Statistical Package for the Social Sciences software (IBM SPSS Inc, Chicago, Illinois, USA). An alpha value of .05 was set for all comparisons, and values were rounded to one decimal place having regard to the tolerance limits of the audio equipment. Between-group comparisons were conducted using independent t-tests, ANOVA and chi-square tests. For the questionnaires, descriptive statistics were used for the closed-item responses, while a combination of thematic analysis, descriptive statistics and Fishers Exact tests were used for open-item responses that required comments.

For each evening, all sound level data from the system that was recorded prior to the performance of the first band or after the performance of the last band were excluded. Similarly, any night on which data collection was incomplete or corrupted by a system error were excluded. For consistency, only measurements of live band music mixed by a sound engineer were included. All nights which involved DJ performances were excluded from further analysis.
6.4 Results

6.4.1 Sound levels

A total of 229 nights of music were measured, however, 65 were excluded either because the data were incomplete, or the evening comprised DJ performances (see table 2). For the remaining 164 nights, the sound level ($L_{Aeq,T}$) was calculated using the following equation:

$$L_{Aeq,T} = 10 \log_{10}(1/T \sum_{i=1}^{n} (T_i \times 10^{L_{Aeq,1min,T_i}/10}))$$

The calculation revealed that five nights were particularly soft, with an $L_{Aeq,T}$ <85 dB and these were therefore classified as outliers. These events consisted of performances by solo singer/song-writers or small folk ensembles and were excluded from further analysis. Four of these nights occurred during the control condition at Venue C, and one occurred in the experimental condition at Venue E. The remaining 159 nights across the study had a mean $L_{Aeq,T}$ of 96.1 dB ($SD = 4.1$), with a range from 87.1 to 104.6 dB. When sound levels from both conditions were combined, the loudest venue, on average, was Venue F, with a mean $L_{Aeq,T}$ of 101.4 dB ($SD = 1.3$). This was followed closely by A ($M = 100.5$, $SD = 2.3$) and B ($M = 99.5$, $SD = 2.2$), with Venues C ($M = 92.5$, $SD = 2.7$), D ($M = 93.4$, $SD = 2.5$) and E ($M = 95.4$, $SD = 2.8$) having considerably lower mean $L_{Aeq,T}$ values. The most common genres were rock and pop, with the highest sound levels recorded on nights of metal, punk or rock performances across all venues.

Sound levels obtained on weekend nights (Friday, Saturday and Sunday) were compared against performances on weekday evenings. Independent $t$-tests revealed a statistically significant difference, with weekend performances ($M = 97.8$, $SD = 3.9$) louder on average than those held on weekdays ($M = 94.0$, $SD = 3.4$), $t(156) = -6.53$, $p <$
.05. Independent *t*-tests were conducted comparing the sound levels in the control and experimental conditions of each venue. The results showed no statistically significant difference in $L_{A_{eq},T}$ between conditions, $p > .05$ in any of the venues (see figure 2).

Table 2. Sound level system targets and nights of measurement in each venue

<table>
<thead>
<tr>
<th>Venue</th>
<th>Target</th>
<th>Nights included</th>
<th>Nights excluded</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Control</td>
<td>Experimental</td>
</tr>
<tr>
<td>A</td>
<td>103</td>
<td>9</td>
<td>14</td>
</tr>
<tr>
<td>B</td>
<td>103</td>
<td>7</td>
<td>10</td>
</tr>
<tr>
<td>C</td>
<td>98</td>
<td>24</td>
<td>8</td>
</tr>
<tr>
<td>D</td>
<td>98(^7)</td>
<td>21</td>
<td>21</td>
</tr>
<tr>
<td>E</td>
<td>99</td>
<td>14</td>
<td>15</td>
</tr>
<tr>
<td>F</td>
<td>103</td>
<td>8</td>
<td>8</td>
</tr>
</tbody>
</table>

Figure 2. Sound levels ($L_{A_{eq},T}$) for six live music venues.

\(^7\) The system target in this venue was initially set at $102\, L_{A_{eq},15\text{min}}$, however, over the first six nights of the experimental condition, this was gradually reduced to 98 by the venue’s sound engineer because was deemed too high.
6.4.2 Sound level system target

Three venues (A, B and F) opted to set the system target at 103 dB $L_{Aeq,15min}$. These were also the venues with the loudest sound levels in both the control and experimental conditions. For the remaining three venues, a system target of $\leq 99$ dB $L_{Aeq,15min}$ was selected, however, in Venue D, it took some time to reach this decision. Initial concerns from the sound engineer led to the decision to set a target of 102 dB: ‘I think 100 might be too limiting for guest engineers, and 104+ might be too high to be effective,’ however, feedback the following night led to the decision to reduce the target to 100 dB, ‘I’ve not even got close to it tonight’. By the 6th performance, however, this was reduced one further step to 98 dB, as the sound engineer felt it was still too high in their venue, “98 is a good level. I hit it last night, but only just.”

In figure 3, the sound level for each night of measurement in the study can be seen. For four of the six venues, all performances in the experimental condition when the system was in use were below the venue’s target. For example, in Venue A, three nights in the control condition exceeded 103 dB $L_{Aeq,T}$, while in the experimental condition, the loudest evening was of 102.6 dB $L_{Aeq,T}$. For this venue, the sound engineer took detailed notes, including the name of each band, start and stop time of performances and whether the sound ‘mix’ was conducted by an in-house or guest engineer. From these records it was found that the three nights exceeding 103 dB $L_{Aeq,T}$ in the control condition were mixed by the in-house engineer, while the loudest night in the experimental condition was mixed collaboratively a guest engineer. Figure 4 shows a graphical representation of the MAM interface the sound engineer would have seen throughout the evening. Here the ‘0’ line of the y-axis represents the 103 dB $L_{Aeq,15min}$ target, with each positive and negative integer representing 1 dB below or above the target, respectively. Here it can be seen that the support act, mixed by the in-house engineer, stayed well below target, while the main
act, mixed by the guest engineer, remained mostly above target, in the ‘red-zone’ of the system’s visual interface.

Figure 3. Sound levels for each night at each venue across conditions.
Figure 4. Graphical representation of the MAM interface during the loudest evening in Venue A, experimental condition, with $L_{A_{eq,1min}}$, $L_{A_{eq,15min}}$, and $L_{A_{eq,60min}}$ values below.

**6.4.3 Dosimetry**

On the two nights in each venue when dosimetry measurements were conducted (12 in total), the $L_{A_{eq,T}}$ values recorded by the five dosimeters ranged from $73.4 \leq 112.3$ dB ($SD = 7.5$, $M = 96.6$). These values were consistent with the levels measured by the system from the sound desk on each night as shown in table 3. In general, the stage was the loudest position across all conditions and venues, with an overall mean of 102.3 dB
CHAPTER 6 RESULTS

(\(SD = 6.6\)), followed by the dance floor \((M = 100.2, SD = 3.6)\) sound desk \((M = 98.2, SD = 4.1)\) and bar \((M = 95.3, SD = 2.9);\) see figure 5). A one-way ANOVA, comparing the \(L_{Aeq,T}\) by dosimeter position, revealed a statistically significant difference between the mean \(L_{Aeq}\) of each position, \(F(4,54) = 453.9, p < .05\). The peak level ranged from 109.2 to 143.5 dB \(L_{Cpeak}\) \((M = 129.0, SD = 6.3)\), exceeding 140 dB on four occasions. In venue A, the stage-positioned dosimeter recorded 140.2 and 142.9 dB \(L_{Cpeak}\) during the control and experimental conditions respectively, while venue B recorded 143.5 dB \(L_{Cpeak}\) for both conditions also from the stage. However, it should be noted that these incidences may have been caused by unintended physical impact resulting from handling or position changes later in the evening.

Figure 5. \(L_{Aeq,T}\) measurements taken by dosimeters in all venues by location.

6.4.4 Daily noise dose

Using the following equation, the exposure at each position was calculated in Pascal squared hours, where \(T\) denotes hours (AS/NZS 1269.1 2005).
\[ E_{A,T} = 4 \times T \times 10^{0.1(L_{Aeq,T} - 100)} \]

The exposure figure was then converted to a noise dose percentage, i.e., noise exposure was expressed as a percentage of the allowable daily ‘noise dose’ permissible in the workplace. Daily noise dosage ranged from as little as 3.0% to 18,794.0% \((M = 1614.9, SD = 3124.0)\), with the greatest exposure coming from the stage in all venues (table 3).

Table 3. Sound level and Daily Noise Dose as recorded by dosimeters in each venue.

<table>
<thead>
<tr>
<th>Venue</th>
<th>Position</th>
<th>(L_{Aeq,T})</th>
<th>Daily Noise Dose (%)</th>
<th>(L_{Aeq,T})</th>
<th>Daily Noise Dose (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Sound Desk (System)</td>
<td>100.8 (99.9)</td>
<td>1579</td>
<td>103.5 (101.7)</td>
<td>3298</td>
</tr>
<tr>
<td></td>
<td>Ticket Desk</td>
<td>89.2</td>
<td>109</td>
<td>91.1</td>
<td>190</td>
</tr>
<tr>
<td></td>
<td>Bar</td>
<td>95.9</td>
<td>511</td>
<td>97.1</td>
<td>756</td>
</tr>
<tr>
<td></td>
<td>Dance Floor</td>
<td>104</td>
<td>3299</td>
<td>104.4</td>
<td>4058</td>
</tr>
<tr>
<td></td>
<td>Stage</td>
<td>108.4</td>
<td>9086</td>
<td>109.1</td>
<td>11976</td>
</tr>
<tr>
<td>B</td>
<td>Sound Desk (System)</td>
<td>103.4</td>
<td>2421</td>
<td>101.9 (100.3)</td>
<td>836</td>
</tr>
<tr>
<td></td>
<td>Ticket Desk</td>
<td>76.8</td>
<td>5</td>
<td>*</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Bar</td>
<td>98.2</td>
<td>731</td>
<td>100.2</td>
<td>565</td>
</tr>
<tr>
<td></td>
<td>Dance Floor</td>
<td>105.6</td>
<td>4018</td>
<td>104.6</td>
<td>1557</td>
</tr>
<tr>
<td></td>
<td>Stage</td>
<td>112.3</td>
<td>18794</td>
<td>110.4</td>
<td>5921</td>
</tr>
<tr>
<td>C</td>
<td>Sound Desk (System)</td>
<td>93.1 (92.3)</td>
<td>245</td>
<td>95.5 (95.3)</td>
<td>459</td>
</tr>
<tr>
<td></td>
<td>Ticket Desk</td>
<td>73.4</td>
<td>3</td>
<td>82.4</td>
<td>22</td>
</tr>
<tr>
<td></td>
<td>Bar</td>
<td>90.3</td>
<td>129</td>
<td>92.3</td>
<td>220</td>
</tr>
<tr>
<td></td>
<td>Dance Floor</td>
<td>95.9</td>
<td>467</td>
<td>96.5</td>
<td>578</td>
</tr>
<tr>
<td></td>
<td>Stage</td>
<td>97.4</td>
<td>659</td>
<td>95.2</td>
<td>428</td>
</tr>
<tr>
<td>D</td>
<td>Sound Desk (System)</td>
<td>95.0 (95.5)</td>
<td>401</td>
<td>95.6 (96.9)</td>
<td>370</td>
</tr>
<tr>
<td></td>
<td>Ticket Desk</td>
<td>86</td>
<td>50</td>
<td>87</td>
<td>51</td>
</tr>
</tbody>
</table>

* No data available due to equipment failure
<table>
<thead>
<tr>
<th>Location</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bar</td>
<td>96</td>
<td>504</td>
<td>96.5</td>
<td>456</td>
</tr>
<tr>
<td>Dance Floor</td>
<td>99</td>
<td>1006</td>
<td>100.4</td>
<td>1118</td>
</tr>
<tr>
<td>Stage</td>
<td>105</td>
<td>4006</td>
<td>102.7</td>
<td>1899</td>
</tr>
<tr>
<td>Sound Desk</td>
<td>(System)</td>
<td>93</td>
<td>260</td>
<td>94.7</td>
</tr>
<tr>
<td>Ticket Desk</td>
<td>97.2</td>
<td>700</td>
<td>95.8</td>
<td>406</td>
</tr>
<tr>
<td>Bar</td>
<td>95.5</td>
<td>470</td>
<td>94.2</td>
<td>281</td>
</tr>
<tr>
<td>Dance Floor</td>
<td>95.8</td>
<td>500</td>
<td>98.5</td>
<td>755</td>
</tr>
<tr>
<td>Stage</td>
<td>92.4</td>
<td>230</td>
<td>98.4</td>
<td>738</td>
</tr>
</tbody>
</table>

6.4.5 **Staff hearing health**

Ninety-three employees completed the demographic questionnaire ranging in age from 19 to 46 years \( M = 28.1, SD = 5.7 \). Forty-six identified as male, 44 as female and three as other. The majority had worked for a brief period in their current respective venue, either less than one year \( n = 44 \), or between two and four years \( n = 42 \); however, seven had worked in their venue for more than five years. Most individuals worked >20 hours/week \( n = 48 \), however the remainder worked either 10 ≤ 20 hrs \( n = 20 \) or < 10 hrs \( n = 25 \) in the venue. Staff worked in a variety of roles, including manager \( n = 20 \), security \( n = 5 \), door attendant \( n = 11 \), sound engineer \( n = 5 \), bar person \( n = 35 \) and glassie (i.e. returning empty glasses to the bar) \( n = 9 \). The remaining eight respondents worked in ‘other’ roles Within the venues, staff were also situated in various locations:
behind the bar \((n = 43)\), on the dance floor \((n = 17)\) or at the ticket desk for each shift \((n = 12)\). Six were located at the sound desk, two in the office, and two more at the street entrance. The remaining 11 worked in a variety of locations, rotating as appropriate.

Most respondents had experienced at least one symptom of hearing damage. Tinnitus was common, with half the employees reporting tinnitus \textit{occasionally} or \textit{sometimes} \((n = 47)\), and 21 \textit{often} or \textit{always}. Twenty-five participants reported \textit{never/rarely} experiencing tinnitus. Just over half the sample had experienced tinnitus or worsening of pre-existing tinnitus during or directly after a work shift in music \((n = 47)\). Furthermore, 27 had experienced hearing dullness, 18 a sensation of blockage in the ears, 16 hearing distortion and 13 had experienced ear pain/otalgia. About one-quarter \((n=26)\) had not experienced any noticeable symptom of hearing injury in association with their work.

Use of hearing protection during work shifts was low, with 41 \textit{never/rarely} using earplugs, 42 \textit{occasionally} or \textit{sometimes}, and only 10 \textit{often} or \textit{always}. Staff were asked to nominate which forms of hearing protection they had used during a shift in the venue. Most had used foam earplugs \((n = 62)\), but other types were much less common; e.g. non-custom, filtered earplugs \((n = 12)\), custom-moulded earplugs \((n = 5)\), in-ear-monitors \((n = 3)\). Table 4 shows data on the availability of hearing conservation options for staff, as well as options they would have preferred if available. Provision of foam earplugs was by far the most commonly used option.

Regarding hearing testing and training, no staff member reported having been offered a hearing test by their employer, though many indicated they would appreciate this being provided by their employer \((n = 38)\). When investigated by venue, only staff within two venues reported having previously received hearing conservation training,
however, for one of these venues the only individual to answer yes was a manager, with no bar staff having received the same such training.

Table 4. Options for hearing conservation staff noted were available or would like to be available within each venue.

<table>
<thead>
<tr>
<th>Method</th>
<th>Available</th>
<th>Wanted</th>
</tr>
</thead>
<tbody>
<tr>
<td>Foam earplugs</td>
<td>85</td>
<td>20</td>
</tr>
<tr>
<td>Non-custom filtered earplugs</td>
<td>13</td>
<td>16</td>
</tr>
<tr>
<td>Custom earplugs</td>
<td>0</td>
<td>21</td>
</tr>
<tr>
<td>Hearing test</td>
<td>0</td>
<td>38</td>
</tr>
<tr>
<td>Hearing training</td>
<td>4</td>
<td>34</td>
</tr>
<tr>
<td>Work-break</td>
<td>38</td>
<td>16</td>
</tr>
<tr>
<td>Shift rotation</td>
<td>26</td>
<td>16</td>
</tr>
<tr>
<td>Reduced shift</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Sound barrier</td>
<td>2</td>
<td>7</td>
</tr>
<tr>
<td>None</td>
<td>5</td>
<td>8</td>
</tr>
</tbody>
</table>

6.4.6 Patron hearing health

Completed surveys were obtained from 268 patrons, with age of respondents ranging from 18 to 65 years ($M = 29.5$, $SD = 10.5$). Gender was a relatively even split between male and female, with a small percentage identifying as ‘indiscriminate/indeterminate/undisclosed’ (see table 5). Frequency of attendance at live-music venues was high overall, with most reporting attendance at least weekly ($n = 60$), fortnightly ($n = 47$) or monthly ($n = 55$). Sixty-seven frequented less often (once every two-to-three months), and the remainder attended venues less than once or twice per year ($n = 39$). In contrast, reported use of hearing protection was low, with most never/rarely using them at a live music event ($n = 191$), 50 respondents used them occasionally or
sometimes, and around one in ten often or always ($n = 27$). Chi-square analysis comparing male and female participants found that females ($n = 110, 76.4\%$) reported never/rarely using hearing protectors more so than males ($n = 80, 67.2\%$), $X^2 = 12.1, p < .05$.

Table 5. Patron demographics.

<table>
<thead>
<tr>
<th>Venue</th>
<th>Gender</th>
<th>Age</th>
<th>Mean</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Female</td>
<td>13</td>
<td>23</td>
<td>-</td>
</tr>
<tr>
<td>B</td>
<td>Male</td>
<td>20</td>
<td>20</td>
<td>1</td>
</tr>
<tr>
<td>C</td>
<td>Other</td>
<td>24</td>
<td>18</td>
<td>-</td>
</tr>
<tr>
<td>D</td>
<td>Mean</td>
<td>27</td>
<td>30</td>
<td>4</td>
</tr>
<tr>
<td>E</td>
<td>SD</td>
<td>34</td>
<td>13</td>
<td>-</td>
</tr>
<tr>
<td>F</td>
<td>Totals</td>
<td>26</td>
<td>15</td>
<td>5</td>
</tr>
</tbody>
</table>

Patrons were asked if they had experienced symptoms of hearing injury during or after attending a gig. As shown in Table 6, a majority responded yes ($n = 198$). Symptoms reported included tinnitus ($n = 146$), hearing dullness ($n = 68$), “not being able to hear as well the next day” ($n = 64$), a blocked sensation in the ears ($n = 60$) and hearing distortion ($n = 49$). The experience of injury was explored using a chi-square test to compare responses of regular vs irregular live music attendees (see table 4). The results showed a statistically significant difference, with more reports of hearing injury amongst regular attendees, $X^2(6) = 14.4, p < .05$. When genders were compared, there was no statistically significant difference in experience of hearing injury between males and females $X^2 (1, N = 263) = .12, p = .73$. 

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Table 6. Patrons reporting a symptom of hearing injury against frequency of attendance.

<table>
<thead>
<tr>
<th>Symptom</th>
<th>Nil (n = 68)</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Never/rarely</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>Once or twice a year</td>
<td>23</td>
<td>34</td>
</tr>
<tr>
<td>Once every 2-3 months</td>
<td>49</td>
<td>66</td>
</tr>
<tr>
<td>Once a month</td>
<td>36</td>
<td>54</td>
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<tr>
<td>Once a fortnight</td>
<td>36</td>
<td>45</td>
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<tr>
<td>Once a week</td>
<td>26</td>
<td>31</td>
</tr>
<tr>
<td>More than once a week</td>
<td>29</td>
<td>33</td>
</tr>
</tbody>
</table>

6.4.7 Listener satisfaction

Patrons at each venue were asked to indicate what they thought “about the sound level tonight” by selecting one of five responses: much too quiet; a little too quiet; just right; a little too loud; or much too loud. Across all venues and conditions, the majority reported them being just right (n = 193). However, a fifth reported them as a little too loud (n = 56), and 16 either a little or much too quiet.

To compare the patrons’ sound level preferences between venues and conditions, responses were recoded: -1 (much too loud); -0.5 (a little too loud); 0 (just right); 0.5 (a little too soft); and 1 (much too soft). These scores were then averaged for each evening, resulting in a single value for the control and experimental condition at each Venue. As can be seen in figure 6, the mean response for most evenings fell close to ‘0’, indicating that on average, attendees were satisfied with the sound level in the venue they attended. In general, there was a trend towards patrons preferring lower volumes, with 9 of the 12 means falling below 0, which indicates a preference for a slightly softer sound level. Little
difference was observed between the control and experimental conditions, except for Venue E where the sound level during the control condition was considered to be louder than in the experimental condition – here eight participants (34.8%) in the control condition reported sound levels to be a little or much too loud, whereas no participants did so in the experimental condition, Fishers Exact $X^2 = .00$, $p < .05$.

Figure 6. The mean and 95% confidence intervals of patron perception of sound levels for each night of dosimetry.
6.7 Discussion

6.7.1 Sound level management

The aim of the study was to investigate the impact of use of a commercial sound level management software, on sound exposure of patrons and staff in small live-music venues. The sound levels were a close match to those previously reported in venues of a similar size, with a mean sound level of 96 dB $L_{Aeq,T}$ (Beach et al., 2013). However, no reduction in mean sound level was observed within any venue as result of system use. While it appears that the system was not effective in reducing the mean sound levels, its use does appear to have reduced the number of evenings during which excessive volumes occurred. During the control condition, on seven nights the sound level exceeded the target that was later implemented by each venue, yet once introduced in the experimental condition, only two nights exceeded the set targets. The reduced incidence of nights of excessively high sound levels is a positive outcome, since these nights present the greatest risk to hearing.

When considering possible explanations for this result, it is helpful to consider the context in which the specific commercial sound level management system used in the study was originally designed, to help sound engineers at music events comply with the regulatory sound level limits stipulated by the relevant government authority. The visual display MAM, therefore, was developed not to reduce patrons’ noise exposure, but rather to assist event organisers to maximise sound levels whilst remaining below a predetermined upper limit. It makes sense, therefore, that the system appears to have been most effective for events with sound levels closer to the target level. It may be that in smaller venues, in which sound levels vary widely and are often below the upper target levels nominated here, the management system becomes less effective in achieving an
overall reduction in sound exposure. This was particularly evident in venue C, in which four nights in the control condition had a sound level below 85 dB $L_{Aeq,T}$ yet once the system was introduced, no events were at this level: the softest level recorded in the experimental condition was 88 dB $L_{Aeq,T}$.

A possible solution may be to modify the design of the visual display. The interface in the system employed in this study focuses the engineer’s attention on the target through a two-colour traffic light system, which may reinforce a perception that the goal is to meet this target, rather than to keep levels from exceeding it. This may have reduced the incidence of both high and low sound levels by encouraging engineers to try to stay at or close to the target value. A different approach to setting the target level may also be required if such systems are is to be used in smaller venues to achieve an overall reduction in sound levels, rather than simply maintaining a maximum cap on levels. Considering the sound levels observed here ranged from below 85 dB to 105 dB $L_{Aeq,T}$, it may be that varying the target on a night-by-night basis is more appropriate than setting a single one-size-fits-all target level for a venue. For example, a venue may decide to set a lower target for a folk gig than for a metal or punk band. Another option would be to modify the design of the MAM interface, so that staying at levels well below, but not at target, were positively reinforced.

Several challenges arose in implementing the sound level management system across the venues, that may be relevant to future research or users of such systems, and that also suggest some caution in application of the results. Firstly, the motivation of each venue’s team often made a considerable difference to how willingly the system was engaged with. It was often observed that in venues where the decision for involvement came from the top down, with minimal involvement of staff, engagement was often reluctant and at times resistant. However, for venues where the team had been involved
at the outset in the process, communication ran more smoothly, and greater use of the management system was observed. It was also noted that difficulties arose when incorporating guest sound engineers, who may not have received the same training or operational incentive for the system’s use. This was evident in one instance, with the in-house engineer faithfully maintaining sound levels below the target in a night of loud volume, but when mixed by the guest engineer, these rapidly rose to stay above the venue set target. These findings emphasise the need for an approach to sound level management that engages all staff in the process, something which can be aided in staff training, and ensuring any new users are educated on its function to be optimally effective.

In general, the results recorded by the sound level management system and the dosimeters were closely matched, all within the tolerance limits of the microphones. The stage position was found to have the highest sound level in each venue, with two exceptions. In these cases, the performing artists were using in-ear- monitors. These devices are either hard-wired or wireless, with each performer receiving their own individual mix, tailored by a monitor mix engineer, directly to their ears via a belt-pack amplifier and in-situ ear speakers (Chasin, 2009). When used appropriately, in-ear-monitors can replace the need for stage monitors or foldback speakers which direct a personalised feed to each the musician during the performance. Because these stage monitors were removed, the sound level on stage could be lowered below the level measured in the audience area or front-of-house position. The increasing use of in-ear monitors could help to further reduce front-of-house sound levels. With the sound engineer no longer competing with the sound delivered by the stage monitors, they can exercise greater control over the levels presented to the audience, and thereby reduce the overall sound levels in the venue.
6.7.2 Hearing Conservation

Regarding the exposure level of different staff within the venues, sound engineers received the greatest sound exposure, with a mean of 98 dB L_{Aeq,T}, and up to 104 dB L_{Aeq,T}. At this dosage, the sound engineer received almost 33 times their daily noise dose from the beginning of the first performance to the end of the last act. The exposure level of bar staff was 95 dB L_{Aeq,T}, which is consistent with the level of 96 dB L_{Aeq,T} previously reported by Guo and Gunn (2005). Given these levels, it is not surprising that of the 93 staff surveyed, 72% had experienced a form of hearing injury during or after a shift, whereas use of hearing protection, by contrast, was low, with only 11% of reporting regular use. At a systemic level, few provisions for hearing conservation were made available to staff by the venues, with none for example, having received a hearing test in the past. These findings are consistent with those from previous research, reporting low adherence to hearing conservation measures, despite the legal requirement to do so, that would ultimately lead to a reduction in staff hearing injury (Guo & Gunn, 2005; Barlow & Castilla-Sanchez, 2012; Kelly et al., 2012). Furthermore, the number of patrons experiencing symptoms of MIHI was also high, with nearly three quarters having experienced at least one symptom after attendance at a live music venue. A consistent finding across studies has been the relatively low use of hearing protection by patrons, again shown here with 71% never or rarely having used them (Bogoch et al. 2005; Gilles et al., 2013). Combined, these results emphasise the need for venues to take action on hearing conservation, so that the hearing needs of both patrons and staff are considered.
6.7.3 Sound level preferences

Most patrons reported being satisfied with the sound levels, with just one-fifth felt reporting them too high. However, the highest number of ‘just right’ ratings (93%) was reported in venues C and D, in which the sound level fluctuated between 93 and 96 dB $L_{Aeq,T}$. In contrast, the lowest proportion of satisfied ratings (76%) was reported for venue F, in which the sound level was far higher, between 100 and 102 dB on the nights when the survey was administered. In the nights of greatest patron satisfaction this level was exceeded, but not in excess. It could be that too far beyond this level, patrons become less satisfied with the intensity. In fact, of the 12 nights of survey conducted, the mean of preferences suggested that in nine cases, patrons preferred a slightly lower volume than what was experienced. These findings are in alignment with similar studies, indicating patron preference for lower sound levels than they are often presented with (Gilles et al., 2014). For instance, only one in six of the 993 patrons of live music venues surveyed by Beach and Gilliver (2019) reported sound levels to be ‘just right’, with the majority dissatisfied and preferencing a lower volume than typically experienced. This led the authors to conclude that rather than emphasising an individualistic approach to hearing conservation in music, encouraging venues to meet the preferences of paying patrons would not only benefit them in terms of customer satisfaction, but potentially from an economic stand-point as well (Beach & Gilliver, 2019). While a significant reduction in mean sound levels was not observed in our study from use of the commercial sound level management system, its effectiveness in eliminating nights of excessively high sound levels may help venues to better meet patrons’ desire for lower sound levels.

Results from this study are to be translated with care to the wider context of the music industry, most relevant to venues of similar size to the ones described here. Limitations existed that impeded the model validity, with variables naturally arising in
the context of live music. For instance, each venue presented with several differences, from the quality of the audio equipment to the acoustics of their band room. Differences were also observed within each venue, with variety in music, sound engineer and patronage. Importantly, the sample size was relatively small, and as they represented a metropolitan base, may have influenced the music captured. Finally, as noted, the motivation and management support for the process was a significant variable to actual implementation. Future studies may benefit from the inclusion of more venues from a wider geographic catchment.

6.8 CONCLUSIONS

Software-based sound level management systems offer a potential solution as a component of a strategy to reduce sound exposure of patrons and staff in live music venues. However, the findings suggest that modifications may be necessary if the focus of the system is to reduce patron and staff sound exposure rather than simply to not exceed legislative sound level limits. Recommended alterations could include greater flexibility in choice of target, matching with context of the performance, or changes to the systems’ visual display so that staying below, not at target, is positively reinforced. Although staff and patrons’ experience of hearing injury symptoms is high, hearing protection use remains low. So too, is the adoption of conservation strategies by venues, which appeared lacking in many instances. It is likely that venue-based solutions, incorporating sound level management systems such as the one employed in this study are a promising means of not only safeguarding the hearing of patrons and staff, but also providing the sound levels many patrons desire and enjoy.
REFERENCES


You could write a song about some kind of emotional problem you are having, but it would not be a good song, in my eyes, until it went through a period of sensitivity to a moment of clarity. Without that moment of clarity to contribute to the song, it’s just complaining.

— Joni Mitchell
7.1 INTRODUCTION

The aim of this thesis was to explore the topic of reducing the risk of hearing injury in the music industry of Australia for different groups of stakeholders. This was done through four discrete studies, each of which engaged with a different stakeholder group within the hearing and live performance music industries. In Chapters 3 and 4, the focus was on the clinical practices used by audiologists with musician clients, and how this might influence use of and satisfaction with musicians’ hearing protectors (MHPs). In Chapters 5 and 6, however, the focus was live-music sound engineers and the use of a sound level management software, 10EaZY, in reducing the risk of hearing injury for patrons and staff was investigated within six live music venues. In this final chapter, the results of each study are consolidated, together with a discussion of the strengths and limitations of each study, their implications, and considerations for future research.
7.2  KEY FINDINGS

7.2.1  Study 1: Preventing hearing injury in musicians: Insights from audiologists and manufacturers reveal need for evidence-based guidelines. (Chapter 3)

The aim of study 1, was to explore the standard of clinical care delivered to musicians in Australia by audiologists and manufacturers of MHPs. Manufacturers of MHPs and audiologists dispensing them were invited to complete two questionnaires. The results showed that the standard of care delivered by audiologists to musicians varied greatly. In many instances, procedures that would likely encourage earplug usage, i.e. training on how to insert them correctly, were rarely performed. Only 35% of the audiologists routinely conducted a hearing test when seeing musicians for hearing protection. While it could be argued that the inclusion of insertion training and hearing tests are not necessary for the make of custom hearing protectors, they aid in the monitoring of hearing, conservation education, and in the case of insertion training, ensure both comfort and fit.

On the topic of fit, it was clear that manufacturers of MHP felt that a good fit was dependent on the quality of the ear impression taken by the audiologist, rather than the manufacturing process. The impression becomes the mould from which the MHP is made, and thus any issue with fit or attenuation can be traced, in-part, to this process. However, when asked as to how manufacturers would like this process to be conducted, responses were disparate. For example, there were different views in relation to jaw placement during the impression (an aspect that can alter the canal shape and volume); the length of canal, and the material recommended for use (Pirzanski, 2006). Similarly, survey results from audiologists showed variety in how they went about many technical aspects of treating musicians, such as the depth of an ear mould, or jaw position during impression
taking. The results of the surveys reported here, therefore, highlight the need for evidence-based, best-practice guidelines surrounding the make and provision of MHP. These would assist audiologists and manufactures to provide MHP in such a way that their use by musicians is optimised, and in turn their success in preventing hearing injury for musicians.

7.2.2 Study 2: Preventing hearing loss in musicians: Exploring person-centred care in the practice of audiology for musicians. (Chapter 4)

Use of person-centred approaches to healthcare have been shown to increase patient satisfaction, improve adherence to rehabilitation and lower anxiety, amongst other benefits (Grenness et al., 2014). This study sought to investigate if a person-centred approach to the care of musicians would increase satisfaction with hearing protectors by musicians, and thereby increase their use and acceptance. This was explored through four conditions, that differed in the clinical practices used by audiologists when treating musicians acquiring MHPs. High levels of satisfaction in participants both with their appointments (97.6%) and hearing protectors (95.2%) led to a ceiling effect, preventing between-group analyses. However, several key findings were noted. Firstly, the risk to hearing injury in musicians was demonstrated, with 92.9% self-reporting their hearing to be at risk. The experienced of hearing injury symptoms during or after a musical rehearsal or performance, was also high, with 81% have experienced tinnitus alone under these circumstances. The most commonly experienced symptom, tinnitus, was also the one that participants most often reported was improved by use of MHP. Other benefits included greater listening comfort, reduced listening fatigue and improved sound quality. The provision of a hearing test was the most positively received aspect across all conditions.
This result was particularly notable since in Study 1, it was found that this procedure was rarely performed by audiologists when seeing musicians for MHP. Exploring goals of the Musician Oriented Scale of Improvement (MOSI), the ability to hear the music of one’s own instrument, and of others, was the most important aspect to guard for musicians when considering hearing protectors. Goals surrounding the maintenance of audio fidelity, even attenuation of sound and the prevention of tinnitus, were also common.

While most musicians were satisfied with their MHP, 14.3% required post-fit modifications to ensure their comfort and fit. Such modifications included re-shaping of the mould to improve insertion depth and comfort, or a reduction in attenuation so that the surrounding music was more audible to the musician. However, the need for modifications were only once self-identified by one participant, with the rest captured by the treating audiologist. This highlights the need for appointment structures, providing space for clinician-client interactions that allow for the identification of any concerns requiring attention. However, as reported in study 1, almost half of audiologists sampled dispensed MHPs without a fitting appointment, and most without any formal validation, verification or follow-up, all of which are processes that would allow for identification of concerns that need to be addressed. While the results of this study did not support the benefits of a person-centred approach to the fitting of MHP, they did support the benefits of earplug usage and of appointment structures that would ensure identifications of any issues that would limit earplug use.

### 7.2.3 Study 3: Risk of hearing injury in live-music sound engineers. (Chapter 5)

Live-music sound engineers (LMSE) are a stakeholder group crucial to the live music industry yet have been relatively neglected by hearing research. Arguably, their
regular high levels of sound exposure at music events, place them at risk of hearing injury (Guo & Gunn, 2005; Butterfield, 2005; Kok, 2015; Gjestland & Tronstad, 2017). In our sample, this was supported, with 96.2% of the 27 participants reporting having experienced at least one sign of hearing injury during or after a work-shift in music. Eighty-one percent had experienced tinnitus, and 40.5% met the criteria for reduced sound tolerance. Furthermore, those who had experienced tinnitus were significantly less tolerant of high volumes than those who had not, highlighting the connection between these symptoms, previously reported in the literature (Hall et al., 2016; Aazh & Moore, 2018). However, the use of hearing protection to prevent these symptoms, or other forms of music-induced hearing injury (MIHI), was low overall, with several respondents commenting that hearing protectors hindered them from being able to successfully perform their job.

Although no significant hearing loss in the speech range (.25 ≤ 8 kHz) was detected in this sample, 18.5% of sound engineers showed a hearing loss in the EHF (9 ≤ 16 kHz). Previous research has indicated this frequency region of hearing to be particularly sensitive to the deleterious effects of noise exposure (Mehrparvar et al., 2014; Ma et al., 2018). In study 3, this was evident when comparing the hearing of frequent and infrequent users of hearing protection. Here a significant difference in hearing thresholds was reported, with infrequent users having worse hearing at 3 kHz, central to the noise notch of the audiogram, and all EHF between 11.25 and 16 kHz. This was most pronounced at 14 kHz, with a mean difference of 18.9 dB HL. Considering ‘frequent’ earplug users were defined as those who used them at least 20% of worktime, it may be that even with incidental use of hearing protectors’ hearing injury due to music is prevented. Taking into account the difficulties that arise when using hearing protectors during sound engineering, it may be that occasional use in this environment is a more
realistic approach to requiring their constancy of use, as would be required in more traditional, occupational noise settings. However, education is greatly needed for this stakeholder group, to help them understand the benefits of earplug usage so that informed decisions surrounding usage can be made. The findings of this study suggest LMSE are indeed at risk of hearing injury due to their occupational sound exposure and would benefit from greater focus from the research community, industry support and training into how to conserve their hearing.

### 7.2.4 Study 4: Preventing hearing injury in patrons and staff of live music venues. (Chapter 6)

Sound levels in live music venues have been recorded at levels that have the potential to cause hearing injury in both patrons and staff (Bogoch, 2005; Guo & Gunn, 2005; Carter 2011; Beach, Gilliver & Williams, 2013). The aim of Study 4, therefore, was to investigate if use of sound level management software, 10EaZY, could lower venue sound levels as a way of reducing risk of MIHI. The overall mean $L_{Aeq,T}$ of the 159 nights recorded was 96.1 dB, with a range from 87.1 to 104.6 dB. However, there was no significant reduction of $L_{Aeq,T}$ in experimental period when the system was in use. Nevertheless, use of 10EaZY did appear to reduce the number of performances in which extreme intensity levels were measured. Considering the software was created to help engineers ensure that the maximum intensity levels were kept below a specific legislated limit, it is not surprising perhaps, that 10EaZY was most effective at doing so in this study, but not in creating an overall reduction in sound level exposure. If the system is to be used for this purpose, modifications to the interface need to be considered, with the
potential for allowing flexibility in its use, such as the $L_{Aeq, 15\text{ min}}$ target set on any given evening.

When sound level exposure was measured using dosimetry, sound engineers displayed the greatest sound exposure of all staff, with a mean of 98 dB $L_{Aeq,T}$ during a shift, and as high as 104 dB. At this intensity, the sound engineer experienced 3298% of their daily noise dose, more than 30 times higher than the permissible daily noise dose. Consistent with this finding, the reporting of hearing injury symptoms by both patrons and staff was high. Seventy-two percent of staff, and 74% of patrons had experienced at least one symptom of MIHI, with tinnitus being the most common in both groups. The use of hearing protectors to mitigate this risk was ow, with 45% of staff and 71% of patrons, never or rarely using them. In general, hearing conservation strategies appeared to be lacking in each venue. For example, all 93 staff members reported they had not been supplied with a hearing test during their employment, even though this is a requirement for any employee regularly exposed to high sound levels in the workplace. The combination of high sound levels and low use of hearing conservation strategies, either by venue or individuals, contributes to the combined risk of hearing injury within live-music venues.

**7.3 Implications**

The findings reported across the studies comprising this thesis confirm that solutions to the prevention and/or reduction of the risk of hearing injury in the music industry are required - yet remain complex. Different approaches are necessary for each stakeholder group identified as being at risk of hearing injury – including patrons, sound engineers, venue staff and musicians, as well as the clinical audiologist providing services. Multiple
approaches were investigated and identified for the various stakeholder groups involved, with the implications for industry discussed more fully below.

7.3.1 Clinical implications

Central to the practice of audiology is the inclusion of a hearing test which measures an individual’s ability to hear sounds at their softest across a range of frequencies. Termed an audiogram, for almost a century the conventional frequencies tested have included .25 to 8 kHz, frequencies important for the comprehension of speech (French & Steinberg, 1947). From a conservation perspective, they also encapsulate the “noise-notch”, a down-turned triangular shape often visible on an audiogram as a sign of NIHL (Axelsson, 1979; Coles, Lutman & Buffin, 2000). However, studies have emerged that advocate for the inclusion of extended-high frequency testing in the standard test-battery of audiology. The benefits of its inclusion include the monitoring of hearing deterioration due to medical treatments, such as cisplatin’s and in early detection of NIHL (Mehrparvar et al., 2011; Mehrparvar et al., 2014; Sulaiman, Husain & Seluakumaran, 2015; Valiente et al., 2016; Lasso de la Vega et al., 2017; Ma et al., 2018). In Study 3, a significant difference in EHF thresholds was found between individuals who did and did not use hearing protectors frequently, which provides a strong argument for the inclusion of EHF as a diagnostic procedure.

The Client Oriented Scale of Improvement (COSI) is a validated tool, commonly used in aural rehabilitation for measuring client outcomes (Dillon, James, Ginis, 1997). This tool guides both clinician and client in creating person-centred, achievable goals, which are followed-up at later appointments for subjective assessment of outcomes. Using the COSI as a model, a new tool, the Musicians Oriented Scale of Improvement
(MOSI) was developed during this thesis to more adequately measure the client outcomes in musicians. This tool guides both musician and audiologist through the creation of personalised goals, centred on hearing conservation. The pilot study of the MOSI presented in Study 2, while not a validation study per se, indicated that it may have aided in the identification of modifications required for some MHP. Furthermore, it is the first tool of its kind tailored for musicians in the space of audiology, creating a platform from which it can be further refined.

7.3.2 Music industry implications

One of the main findings of this research was the frequent reporting of symptoms of hearing injury reported by patrons and staff of live music venues. However, the use of hearing protection as a means of reducing risk was low. As outlined in study 4, the sound levels measured in the six live-music venues were significant and, on many evenings, capable of causing harm to the auditory system. Interestingly, questionnaire responses by patrons indicated as many as one-fifth would prefer sound levels to be lower. However, regarding the music venues measured in this study, results from the patron surveys that were conducted on the dosimeter nights at the six venues, we found that 9 out of 12, the patron preference for volume was below what was recorded by the measurements system. This is consistent with several other studies reporting patrons to prefer slightly lower sound levels than experienced in both an Australian music context, and abroad (Tereping, 2015; Beach & Gilliver, 2019). It may be, therefore, that a slight reduction in sound levels not only serves the music industry by way of hearing injury prevention, but in increasing enjoyment of patrons. Though an overall reduction in mean sound levels could not be demonstrated as a direct result of using the sound level management software, 10EaZy,
reducing nights of extreme volume through its use were shown. Considering patronage underpins the economic viability of live music venues, satisfying customers with sound levels they prefer while preserving the integrity of a musical performance, would be beneficial to all parties.

7.4 STRENGTHS AND LIMITATIONS

The research presented in this thesis focused upon reducing the risk of hearing injury within the live music industry, either through the improvement of clinical care to musicians, or the use of hearing conservation strategies in indoor live music venues. The four studies used mixed methodology, combining the strengths of quantitative and qualitative data to complement one another. An example of the benefit of this combined approach is shown in study 2. No statistically significant finding between treatment conditions was noted in the comparative analysis, yet the qualitative analysis revealed that the provision of a hearing test was the most positively received aspect of clinical care by musicians. In this way, the use of both quantitative and qualitative data sources maximised the exploration of each topic.

Another strength of the research was the attempt to incorporate all stakeholders involved in the live music industry, and to do so in a real-world setting. Study 2 explored how musicians could best be supported in using hearing protectors, Study 3 documented the hearing of LMSE, and Study 4 explored the experience of staff and patrons in live music venues. Study 4 relied on the involvement of multiple venue stakeholders: management, venue owners, sound engineers, and staff. Because the study was conducted within a real-world environment, instead of a laboratory, the findings are directly applicable to the settings in which they were obtained.
There were several limitations that should be noted in interpreting the findings. Overall, each study had relatively low sample numbers, which impacted statistical analysis in some studies, and in turn, generalisability of any findings. In the case of Study 1 for example, there was a very low uptake of only 35 audiologists from the 2500 who were invited to complete the survey. Furthermore, sampling bias may have influenced the results, with many respondents displaying a high level of musical experience, suggesting a personal interest in the topic that the broader audiology community may not share. In Study 2, the low number of musicians performing head-connecting instruments may have influenced findings surrounding the occlusion effect, while in general the small sample contributed to the lack of significantly different findings across conditions in the experiment.

In conducting study 4 within a real-world setting, variables were introduced outside the control of the researcher. Some variables were between venues, such as room capacity, quality of sound equipment or amount of sound-absorbing materials. Within venue variability included elements such as patronage on any given night and the line-up of the performing artists. This variability may have reduced the generalisability of the model to the broader live music context. Furthermore, the motivation of the sound engineers at each venue varied according to personal interest and in some cases, the attitude of venue managers. This led to some venues following the protocol more closely than others, and generation of more data in those venues where staff were more eager to participate.
7.5 FUTURE DIRECTIONS

A consistent finding across this research was the need to raise awareness of all stakeholders to the risks of hearing injury and the steps they can take to reduce that risk. Results from study 1 and 2 confirmed that there was significant variability in the approaches taken by audiologists in dealing with musicians and MIHI, and that a more consistent approach could be achieved through guidelines and education. In Study 3, it became apparent that LMSE were often not provided with any training in aspects of hearing conservation or protection, either for themselves or the hearing of the patrons within the venues. Including these topics in the tertiary training of sound engineers would may improve uptake of hearing conservation measures and the responsible service of sound. Similarly, in Study 4, few staff reported receiving hearing training or protection from their employer. Taken together, the lack of information and training, specifically about the risks of hearing injury and steps to reduce that risk, and general hearing awareness displayed in the music industry by multiple stakeholders raises concerns for future research. Directions this may benefit in taking would include the development of workplace changes to incorporate hearing conservation measures and engagement of industry in defining appropriate solutions for the music industry.

The results of study 4 suggest that there is a need for continued exploration into sound level management systems within live music events. As outlined by Beach et al (2018), several solutions for sound level management exist, with most falling into one of two streams: top-down solutions, such as national legislation mandating sound level limits; or bottom-up solutions, such as the software management systems explored in this thesis. However, more research is needed to identify which solutions are most effective in bringing about change. Several studies have indicated that even with legislation in place, uptake of conservation strategies by venues remains low (Guo & Gunn, 2005;
Barlow & Castilla-Sanchez, 2012; Kelly et al., 2012). An alternative approach has been tied in the Netherlands; a ‘hearing covenant’ between relevant music stakeholders, which came together in 2011 to agree upon terms that would allow for the protection of patrons’ ears, alongside the preservation of music performance integrity. This industry-led solution brought together stakeholders from advocacy groups, government bodies and music industry representatives (e.g. promoters and venue owners), agreeing upon an upper limit of 103 dB $L_{Aeq,15min}$ (Mulder, 2015). Further research comparing the various approaches to sound level management is required, to help inform industry as to what would be best-practice in providing safer sound levels in live music venues.

When considering how best to approach the complex issue of reducing risk of hearing injury in the music industry, it is vitally important to consider the cultural norms that are associated with loud music. As stated by Blesser (2008a), ‘excessive loudness serves a function.’ It is not without reason that individuals seek out and enjoy loud music, with physiological benefits mimicking in many ways, the reward pathways stimulated by food, sex and drugs (Blood & Zatorre, 2001; Blesser 2008b; Salimpoor et al., 2015). Research into the desire for high sound levels in staff and venue owners has also suggested that that environmental masking, atmosphere creation and increased alcohol consumption are benefits, with one element repeatedly stated; expectation (Vogel et al., 2009; Welch & Fremaux, 2017). Where loud music is continually paired with the positive rewards mentioned above, classical conditioning occurs leading to an acculturation process of acceptance and expectance of loud music (Welch & Fremaux, 2017). If we are to see a reduction in sound level exposure of patrons and staff in live music spaces, it may be that first addressing the culture that supports the continued thrive for more volume is needed.
7.6 CONCLUSIONS

This thesis explored the topic of hearing injury prevention in the music industry through four discrete studies. Combined, the findings support previous research indicating that a wide range of stakeholders, including staff, musicians, and patrons are at risk of hearing injury due to their sound level exposure. Hearing assessments of sound engineers working within these spaces demonstrated the effect that high sound levels can have upon the EHF hearing. It is recommended that EHF testing be included in the test battery for anyone regularly music exposed to monitor hearing. Furthermore, research into what defines clinical best practice for musicians hearing care could aid in optimising hearing protection use in this group. Across all stakeholders, reported uptake of hearing protectors, general awareness of the risks of hearing injury and means of prevention, was low. This was seen at both an individual and systemic level. In conclusion, both the hearing and music industry would benefit from further research into the complex needs of the music industry, and development of best-practice codes to guide practice.
REFERENCES


APPENDICES

APPENDIX A: HREC APPROVAL LETTERS

Appendix A contains Human Research Ethics Committee Approval letters from two institutions where approval was sought. Studies 1 and 2 were overseen by the School of Health Sciences Human Ethics Advisory Group from the University of Melbourne, while Study 3 and 4 were overseen by the Human Research & Ethics Committee of the Royal Victorian Eye and Ear Hospital.
Appendix A-1: The University of Melbourne Human Research Ethics Committee approval letter

01 July 2016

Mr D.P. Power
Audiology and Speech Pathology
The University of Melbourne

Dear Mr Power

I am pleased to advise that the School of Health Sciences Human Ethics Advisory Group has approved the following Minimal Risk Project:

Project title: Optimisation of hearing care for musicians
Researchers: Miss S McInerney, Dr C.M. Greenness, Mr D.P. Power
Ethics ID: 1646388

The Project has been approved for the period: 01-Jul-2016 to 31-Dec-2016.

It is your responsibility to ensure that all people associated with the Project are made aware of what has actually been approved.

Research projects are normally approved to 31 December of the year of approval. Projects may be renewed yearly for up to a total of five years upon receipt of a satisfactory annual report. If a project is to continue beyond five years a new application will normally need to be submitted.

Please note that the following conditions apply to your approval. Failure to abide by these conditions may result in suspension or discontinuation of approved and/or disciplinary action.

(a) Limit of Approval: Approval is limited strictly to the research as submitted in your Project application.

(b) Amendments to Project: Any subsequent variations or modifications you might wish to make to the Project must be notified formally to the Human Ethics Advisory Group for further consideration and approval before the revised Project can commence. If the Human Ethics Advisory Group considers that the proposed amendments are significant, you may be required to submit a new application for approval of the revised Project.

(c) Incidents or adverse effects: Researchers must report immediately to the Advisory Group and the relevant Sub-Committee anything which might affect the ethical acceptability of the protocol including adverse effects on participants or unforeseen events that might affect continued ethical acceptability of the Project. Failure to do so may result in suspension or cancellation of approval.

(d) Monitoring: All projects are subject to monitoring at any time by the Human Research Ethics Committee.

(e) Annual Report: Please be aware that the Human Research Ethics Committee requires that researchers submit an annual report on each of their projects at the end of the year, or at the conclusion of a project if it continues for less than this time. Failure to submit an annual report will mean that ethics approval will lapse.

(f) Auditing: All projects may be subject to audit by members of the Sub-Committee.

Please quote the ethics registration number and the name of the Project in any future correspondence.

On behalf of the Ethics Committee I wish you well in your research.

Yours sincerely,

[Signature]

Prof Nicola Santamaria - Chair
School of Health Sciences Human Ethics Advisory Group

Melbourne School of Health Sciences
The University of Melbourne, Victoria 3010 Australia
T: +61 3 8344 4171  F: +61 3 8344 5291
W: http://healthsciences.unimelb.edu.au/
Appendix A-2: Royal Victorian Eye and Ear Hospital Human Research Ethics Committee approval letter

21 May 2015

Professor Robert Cowan
The HEARing CRC & HearWorks
550 Swanston Street
Carlton Vic 3053

Dear Professor Cowan

HREC Reference Number: 15/1225H
Introducing HEARSmart to Music Venues: A Pilot Study

Thank you for submitting the above research project for ethical review. This project was considered by the Royal Victorian Eye & Ear Hospital (RVEEH) Human Research & Ethics Committee at its meeting held on 23 April 2015.

I acknowledge receipt of the revised Participant Information & Consent Form. I am pleased to inform you that ethical approval has now been granted for this project. This letter constitutes ethical approval only.

The project number 15/1225H was allocated, and this number should be used in all future correspondence. The following documents have been reviewed and approved:

- Participant Information and Consent Form, v4 dated 21 May 2015
- Protocol, v1 dated 30 Mar 2015
- Questionnaires, 31 Mar 2015

The following Researchers were approved: (subject to RVEEH appointments and scope of practice for researchers where required):
- Prof Robert Cowan
- Paul O’Halloran
- Dr Elizabeth Beach
- Siobhan McGinnity
- Meghan Stewart

The Human Research & Ethics Committee of the Royal Victorian Eye & Ear Hospital is constituted and operates in accordance with the National Health & Medical Research Council (NHMRC) National Statement on Ethical Conduct in Human Research (2007) and the NHMRC Australian Code for Responsible Conduct of Research (2007).

The Committee requires an annual progress report, and must approve any proposed amendments to the protocol. All serious or unexpected adverse effects on participants or any unforeseen events that might affect continued ethical acceptability of the trial must be reported to the Committee.

The Committee requires you to preserve the confidentiality of information about research subjects, and to ensure the confidentiality of records. Information obtained for your research that is confidential or personal must not be used for purposes other than those specified in the approved protocol.

Ethical approval is valid from the date of this letter until 23 April, 2020. At the end of this period, or at the conclusion of the research, a final report is required along with a copy of any publications.

On behalf of the Committee, I wish you every success with your project.

Yours sincerely,

Kerryn Baker
Secretary
Human Research & Ethics Committee

The Royal Victorian Eye & Ear Hospital
32 Gisborne Street
East Melbourne
Victoria 3002 Australia
Locked Bag 8
East Melbourne
Victoria 8002 Australia
T. +61 3 9929 8666
TTY. +61 3 9929 8552
F. +61 3 9663 7203
info@eyeandear.org.au
www.eyeandear.org.au
ABN 81 863 814 677
Research Ethics Office
T. +61 3 9929 8525
ethics@eyeandear.org.au
APPENDIX B: QUESTIONNAIRES

The following comprise the questionnaires used in each respective study.

**Study 1**

Appendix B-1:  Audiologist questionnaire
Appendix B-2:  Manufacturer questionnaire

**Study 2**

Appendix B-3:  Pre-appointment questionnaire
Appendix B-4:  Exit-interview questionnaire

**Study 3**

Appendix B-5:  The hearing health of live music sound engineers

**Study 4**

Appendix B-6:  Staff demographic questionnaire
Appendix B-7:  Staff sound level questionnaire
Appendix B-8:  Patron sound level questionnaire
Appendix B-1: Study 1 - Audiologist Questionnaire

DEMOGRAPHIC INFORMATION

What is your date of birth?

What is your gender?
( ) Male
( ) Female
( ) Interdeterminate/intersex/unspecified

What postcode do you live in?

What is your current position or job title? (tick all that apply)
( ) Clinician
( ) Manager
( ) Researcher
( ) Other (please describe)

For how many years have you been working as an audiologist?

Do you have any musical training/experience? If yes, please describe how many years and to what capacity.

SERVICE DELIVERY

Do you have any non-custom-fitted or one-size-fits-all earplugs available in stock at the clinic where you work?
( ) Yes (please describe)
( ) No

In your clinic, do you have a clinical protocol tailored for the hearing care of musicians?
( ) Yes (please describe)
( ) No

When a musician attends the clinic seeking custom-fitted hearing protectors, which of the following clinical procedures are carried out? (Select all that apply)
( ) Otoscopy
( ) Pure tone audiometry
( ) Extended high frequency audiometry
( ) Tympanometry
( ) Speech discrimination testing (AB words)
( ) Speech in noise testing (please specify)
( ) Acoustic Reflex Testing
( ) Loudness discomfort testing
APPENDIX B

( ) OAE’s (please specify)
( ) Other (please describe)

Do you request hearing tests for musicians be conducted after a period of relative silence?
( ) Yes (please specify)
( ) No

Do you routinely fit custom-fitted musicians’ hearing protectors over the counter or in a follow-up appointment?
( ) Over the counter, no appointment
( ) In an appointment
( ) Other (please describe)

Do you provide musicians with any counselling or education on hearing in the music industry (i.e. handouts on noise and hearing loss)? Please describe.

Have you ever completed an up-skilling course or further education specifically related to the service delivery of hearing care for musicians?
( ) Yes
( ) No

[If yes]

Please describe the training you received.

Would you find an up-skill course related to the service delivery of hearing care for musicians helpful?
( ) Not at all helpful
( ) Not very helpful
( ) Somewhat helpful
( ) Helpful
( ) Very helpful

How confident do you feel in providing services for musicians (i.e. assessments, education, advice on hearing protection)?
( ) No confidence
( ) Slightly Confidence
( ) Confidence
( ) Very Confidence

Does your clinic have any professional relationships either with earplug manufacturers, musicians or related professional bodies?
( ) Yes (please describe)
( ) No
( ) Unsure
IMPRESSION TAKING & ORDERING

Do you prefer to use a foam or cotton block during impression taking?
( ) Foam block
( ) Cotton block
( ) Other (please describe)

What impression material do you use for custom-fitted musicians’ hearing protectors?
( ) Low viscosity
( ) High viscosity
( ) Other (please describe)

What impression technique do you use for custom-fitted musicians’ hearing protectors?
( ) Closed mouth impression
( ) Open mouth, stationary
( ) Open mouth, stationary with bite-block
( ) Open mouth, with motion
( ) Other (please describe)

What canal length do you prefer for custom-fitted musicians hearing protectors (Where short refers to up to the first bend, medium - between the first and second bend, and long - beyond the second bend)?
( ) Short
( ) Medium
( ) Long
( ) Other (please describe)

Do you taper the canal end of your custom-fitted musicians’ earplugs?
( ) Yes
( ) No
( ) Unsure

What material do you prefer custom-fitted musicians’ hearing protectors to be made in?
( ) Hard Acrylic
( ) Shore 25
( ) Shore 40
( ) Shore 70
( ) Unsure
( ) Other (please describe)

What manufacturer of custom-fitted hearing protectors do you most frequently recommend for musicians and why?

Have you noticed any differences between the various brands/manufacturers of custom-made musicians’ earplugs?

In your opinion, what technical aspects define a ‘good’ custom-fitted musician earplug?
Are you aware of acoustic mass measurements of sound bores?

( ) Yes
( ) No
( ) Unsure

Are you aware of any filters with ‘occlusion reducing’ properties?

( ) Yes
( ) No
( ) Unsure

Which of the following custom hearing protectors have you ordered for musicians?

( ) Custom-fitted, filtered musicians’ earplugs
( ) Custom-fitted, vented musicians’ earplugs
( ) Custom-fitted, electronic musicians’ earplugs
( ) Custom-fitted in-ear-monitors
( ) Other (please describe)

Have you ordered any custom-fitted musician hearing protectors with handles or other features to assist with management (e.g., neck cord)? Please describe.

What level of attenuation do you most frequently prescribe for musicians?

In what circumstances might you prescribe 10 dB or less attenuation?

In what circumstances might you prescribe 15 dB attenuation?

In what circumstances might you prescribe 25 dB or more attenuation?

What instrument do you find the most difficult to prescribe hearing protectors for and why?

In your opinion, what are the main impediments and barriers to the uptake and use of hearing protectors by musicians?

VALIDATION & VERIFICATION

Do you verify your custom-fitted musicians’ hearing protectors in clinic?

( ) Yes
( ) No
( ) Unsure

[If yes]

What methods of verification do you use?

Do you validate your custom-fitted musicians’ hearing protectors in clinic, i.e. assess client satisfaction or usage?
( ) Yes
( ) No
( ) Unsure

[If yes]

What methods of validation do you use?

After the fitting of custom-fitted musicians’ hearing protectors, do you follow-up on outcomes with the client? (I.e. via phone, email or appointment)
( ) Yes
( ) No
( ) Unsure

If known, what is the remake rate of custom-made musicians’ earplugs in the clinic where you work (i.e., approximately what percentage of your customers require their impressions to be retaken and/or their earplugs to be remade due to unsatisfactory fitting)?

Before we leave you, your opinion on this topic is important to us. Do you have any other comments you would like to make about the manufacturing of custom-fitted musicians’ hearing protectors?
Appendix B-2: Study 1 - Manufacturer Questionnaire

MANUFACTURING

Does your company make custom-fitted musicians’ earplugs?
( ) Yes
( ) No

[If Yes, survey is continued, if No – participant is taken to Thank You page]

What type(s) of hearing protectors does your company provide/make for musicians’? (Select all that apply)
( ) One-size-fits-all filtered
( ) Custom-fitted musicians’
( ) Custom-fitted vented
( ) Custom-fitted electronic
( ) Custom-fitted in-ear-monitors
( ) Other (please describe)

For how many years has your company been involved in the making of custom-fitted musicians’ hearing protectors?

Do you use 3D scanning and/or computer modelling for making custom-fitted musicians’ hearing protectors?
( ) Yes
( ) No
( ) Other (please describe)

What brand(s) of filter are used and why? (Please list all brands used, and if more than one, please state your company’s first recommendation)

Are the filters verified before leaving the manufacturing plant?
( ) Yes
( ) No
( ) Unsure

[If yes]

Please describe the filter verification process.

Does your company have a recommended diameter for the sound bore of custom-fitted musicians’ hearing protectors?
( ) Yes
( ) No
( ) Unsure

Is the acoustic mass of the earplug measured prior to leaving the manufacturing plant?
( ) Yes
( ) No
( ) Unsure
Comments

[If yes]

Please describe how the acoustic mass is measured.

What design options are available to the client when ordering custom-fitted musicians’ hearing protectors for your company? (I.e. optional handle or neck cord)

Does your company have any recommendations on how to reduce the occlusion effect of custom-fitted musicians’ hearing protectors?

Does your company have any recommendations available to audiologists or musicians on choosing appropriate levels of attenuation? (e.g., based on exposure, instrument or role in the industry?)

Does your company have a breakdown of its customer base of musicians using custom-fitted musicians’ hearing protectors (i.e. gender, age, instrument, attenuation prescribed)?

If known, what is your remake rate of custom-made musicians’ hearing protectors (i.e., approximately what percentage of your customers require their impressions to be retaken and/or their earplugs to be remade due to unsatisfactory fitting)?

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**SERVICE DELIVERY**

Does your company recommend the use of a foam or cotton oto-block during impression taking?
( ) Foam block
( ) Cotton block
( ) Other (please describe)
( ) Unsure
( ) No recommendation

Does your company recommend the use of a particular impression material during impression taking?
( ) Low viscosity
( ) High viscosity
( ) Other (please describe)
( ) Unsure
( ) No recommendation

Does your company recommend audiologists use a particular method of impression taking?
( ) Closed mouth impression
( ) Open mouth, stationary
( ) Open mouth, stationary with bite-block
( ) Open mouth, with motion
( ) Other (please describe)
( ) Unsure
( ) No recommendation

**Does your company recommend the earplugs be made in a particular material?**
( ) Hard Acrylic
( ) Shore 25
( ) Shore 40
( ) Shore 70
( ) Unsure
( ) Other (please describe)

**Does your company recommend a canal-length for the earplugs?** (I.e. short - up to the first bend, medium - between the first and second bend, and long - beyond the second bend)
( ) Short
( ) Medium
( ) Long
( ) Marked as per impressions
( ) Unsure
( ) No recommendation

**Does your company recommend, or routinely perform, tapering of the canal portion of the earplug?**

( ) Yes (please describe)
( ) No
( ) Unsure
( ) No recommendation

**Does your company have a relationship with a professional music body or audiology profession in regard to the hearing care of musicians or the making of custom-fitted musicians’ hearing protectors?**
( ) Yes (please describe)
( ) No
( ) Unsure

[If No or Unsure]

**Do you think this would be helpful in anyway?**
( ) Not at all helpful
( ) Not very helpful
( ) Somewhat helpful
( ) Helpful
( ) Very helpful

[If Yes]
Do you find this relationship helpful?
( ) Not at all helpful
( ) Not very helpful
( ) Somewhat helpful
( ) Helpful
( ) Very helpful

Before we leave you, your opinion on this topic is important to us. Are there any other comments you would like to make about the manufacturing of custom-fitted musicians’ hearing protectors?
Appendix B-3: Study 2 - Pre-appointment Questionnaire

YOU AND YOUR HEARING

What is your gender?
( ) Female
( ) Male
( ) Indeterminate/intersex/unspecified

What is your date of birth?

Have you had a hearing test before, if so, what was the most recent result?
( ) Yes, normal hearing in both ears
( ) Yes, hearing loss in one ear
( ) Yes, hearing loss in both ears
( ) Yes, but I don’t know the result
( ) No, I have not had a hearing test

[If yes]
How frequently do you get your hearing tested?

Do you have a history of ear infections?

Have you ever seen an Ear Nose and Throat specialist?

Have you ever had surgery in or around your ears?

Is there a history of hearing loss in your family?

Have you been exposed to loud noise apart from your work in the sound/music industry?
( ) Yes (please describe)
( ) No
( ) Unsure

Do you, or other people notice any problems with your hearing?
( ) Yes (please describe)
( ) No
( ) Unsure

Do you have difficulty following conversation in background noise?
( ) Yes
( ) No

Are you sensitive to loud sounds?
( ) Yes
( ) No
APPENDIX B

**Do your ears ever feel blocked or dull?**

( ) Yes (please describe)

( ) No

**Do you ever experience pain in or around your ears?**

( ) Yes (please describe)

( ) No

**Tinnitus is defined as any sound that a person can hear internally that is not present externally. It may be heard as a buzzing, ringing, whistling, hissing or pulsing sound. Have you ever experienced tinnitus?**

( ) Never/almost never

( ) Occasionally

( ) Sometimes

( ) Frequently

( ) Always/almost always

( ) Unsure

[If present]

**How would you rate the severity of your tinnitus?**

( ) Mild

( ) Moderate

( ) Severe

**Have you ever experienced the following or a worsening of the following after a performance or rehearsal? (select all that apply)**

( ) Ringing in the ear (tinnitus)

( ) Hearing dullness

( ) Blocked sensation in the ears

( ) Pain in the ears

( ) Sound distortion

( ) Other (please describe):

( ) None of the above

**YOUR WORK AND TRAINING**

**How would you describe your work in the music industry?**

( ) Professional (full-time)

( ) Professional (part-time)

( ) Freelance

( ) Amateur/recreational

( ) Other (please describe):

**What instrument(s) do you play?**

**What music genre/s do you mostly play?**

**Have you completed or are you enrolled in any music-related training?**

( ) Yes (please describe):

( ) No
On average, how many times do you perform each month?
( ) About once a month
( ) 1-5 times a month
( ) 5-10 times a month
( ) More than 10 times a month

On average, how many hours per week would you rehearse, both privately and with others?
( ) Less than 1 hour per week
( ) 1-5 hours per week
( ) 5-10 hours per week
( ) 10-15 hours per week
( ) More than 20 hours per week

Please describe the various roles you perform as a musician (i.e. performer, teacher, writer).

What proportion of your time do you spend listening to, performing or producing music? (include scenarios like rehearsal, performances, sound checking, recreational listening)
( ) 0-25%
( ) 26-50%
( ) 51-75%
( ) 76-100%

Have you received any education on how to protect your ears as a musician?
( ) Yes (please describe)
( ) No

Has your employer or a client ever provided you with the following? (select all that apply)
( ) Payment to undergo a hearing test
( ) Education of training opportunities related to hearing
( ) Hearing protectors (e.g. earplugs)
( ) None of the above

HEARING PROTECTION

Do you believe your hearing is at risk working as a musician?
( ) Yes
( ) No
( ) Unsure

Have you worn hearing protectors before?
( ) Yes
( ) No

[If yes]
Please describe why (select all that apply)
( ) I haven’t thought about it before
( ) I’m not at risk of hearing damage
( ) The risk of hearing damage is part of the job
( ) Earplugs are uncomfortable
( ) Earplugs prevent me from being able to do my job
( ) Earplugs are a hassle
( ) Earplugs are too noticeable
( ) Custom-made earplugs are too expensive
( ) Other (please describe):

How often would you wear hearing protectors?
( ) Never/almost never (less than 10% of the time)
( ) Occasionally (less than 50% of the time)
( ) Sometimes (around 50% of the time)
( ) Frequently (more than 50% of the time)
( ) Almost always/always (more than 90% of the time)

Have you always worn hearing protectors in music?
( ) Yes
( ) No

Why did you start to use hearing protectors?

What type of hearing protectors have you worn? (select all that apply)
( ) Tissue/cotton wool in the ear
( ) Foam earplugs
( ) Non-custom, filtered earplugs
( ) Custom-made earplugs
( ) Custom-made vented earplugs
( ) Custom-made electronic earplugs
( ) In-ear monitors
( ) Custom in-ear monitors
( ) Acoustic screens
( ) Other (please describe):
( ) None of the above

Please describe the situation(s) you have worn hearing protectors in (e.g. when performing).

Why do you choose, or would you choose, to wear hearing protectors? (select all that apply)
( ) To protect my ears from hearing loss
( ) To protect my ears from tinnitus
( ) I have hearing loss and I don’t want it to get worse
( ) I have tinnitus and I don’t want it to get worse
( ) To reduce the severity of my hearing-related symptoms after a shift (rehearsal/performance)
( ) My boss requires me to do so
( ) Other:
Appendix B-4: Study 2 – Exit-Interview Questionnaire

HEARING PROTECTION USE

Since your fitting appointment, how many times have you worn your hearing protectors?

( ) I have not worn my hearing protectors
( ) Less than 5 times
( ) 5 to 10 times
( ) More than 10 times

[If yes]
Please describe why this may be:

In what situations have you worn your hearing protectors?

( ) Private rehearsals
( ) Group rehearsals
( ) Teaching
( ) Performing – solo
( ) Performing – group
( ) Other:

How useful did you find your hearing protectors overall?

( ) Very useful
( ) Somewhat useful
( ) Not very useful
( ) Not at all useful

In which situation(s) did you find your hearing protectors most useful?

In which situation(s) did you find your hearing protectors least useful?

Did you experience any difficulties with the use of your hearing protectors (i.e. discomfort, made sounds too soft etc.)?

Did you experience any benefits to the use of your hearing protectors (i.e. experienced less tinnitus after a show)?

Did you require any modifications to your hearing protectors (i.e. change in filter or mould)?

How satisfied are you with the fit of your hearing protectors (i.e. comfort, retention etc.)?

( ) Very satisfied
( ) Somewhat satisfied
( ) Neither satisfied nor dissatisfied
How satisfied are you with the sound quality of your hearing protectors (i.e. ability to hear your instrument, blend with others etc.)?
( ) Very satisfied
( ) Somewhat satisfied
( ) Neither satisfied nor dissatisfied
( ) Somewhat dissatisfied
( ) Very dissatisfied

How satisfied are you with your hearing protectors overall?
( ) Very satisfied
( ) Somewhat satisfied
( ) Neither satisfied nor dissatisfied
( ) Somewhat dissatisfied
( ) Very dissatisfied

SERVICE DELIVERY

How satisfied were you with your hearing appointments?
( ) Very satisfied
( ) Somewhat satisfied
( ) Neither satisfied nor dissatisfied
( ) Somewhat dissatisfied
( ) Very dissatisfied

Did you feel you received adequate information on your hearing and music exposure to inform your decision on hearing protectors?
( ) Very satisfied
( ) Somewhat satisfied
( ) Neither satisfied nor dissatisfied
( ) Somewhat dissatisfied
( ) Very dissatisfied

Out of the hearing appointments, what did you find most useful?

Was there anything you believe could have been done better?

Would you recommend the use of hearing protectors to a colleague or friend?
( ) Yes
( ) No
( ) Unsure

In general, what do you think could be done to help protect the hearing of musicians in the music industry?
Appendix B-5: Study 3- The Hearing Health of Live Music Sound Engineers

YOU AND YOUR HEARING

What is your date of birth?

What is your gender?
( ) Male
( ) Female
( ) Indeterminate/intersex/unspecified

What hand do you write with?
( ) Left
( ) Right
( ) Both

What is your postcode?

Have you had a hearing test before and if so, what was the most recent result?

[If yes]
Do you have difficulty following conversation in background noise?
( ) Yes
( ) No

Do you have a history of ear infections?
( ) Yes
( ) No

Have you ever seen an Ear Nose and Throat specialist for your ears?
( ) Yes (please describe reason)
( ) No

Have you ever had surgery in or around your ears?
( ) Yes (please describe)
( ) No

Is there a history of hearing loss in your family?

Have you been exposed to loud noise apart from your work in the sound/music industry?
( ) Yes (please describe)
( ) No

Do you have difficulty following conversation in background noise?
( ) Yes
( ) No
Are you sensitive to loud sounds?
( ) Yes
( ) No

Do your ears ever feel blocked or dull?
( ) Yes (please describe)
( ) No

Do you ever experience pain in or around your ears?
( ) Yes (please describe)
( ) No

Tinnitus is defined as any sound that a person can hear internally that is not present externally. It may be heard as a buzzing, ringing, whistling, hissing or pulsing sound. Have you ever experienced tinnitus?
( ) Never/almost never
( ) Occasionally
( ) Sometimes
( ) Frequently
( ) Always/almost always
( ) Unsure

[If Occasionally, Sometimes, Frequently or Always/almost always]

How would you rate the severity of your tinnitus?
( ) Mild
( ) Moderate
( ) Severe

During or after a work shift have you ever experienced the following symptoms (or an increase in these symptoms)?
( ) Ringing in the ears
( ) Hearing dullness
( ) Blocked sensation in the ears
( ) Pain in the ears
( ) Sound distortion
( ) Other (please describe)
( ) None of these

YOUR WORK AND TRAINING

Have you completed or are you enrolled in any of the following courses or training programs in sound engineer? (Select all that apply)
( ) I haven’t completed any formal training/courses, i.e. self-taught
( ) On the job training
( ) Apprenticeship
( ) Certificate course
( ) Diploma course
( ) University degree
( ) Postgraduate university degree

[If Certificate course, Diploma course, University degree, OR Postgraduate university degree]
What is the name of the institution/s you completed or will complete your training through?

What was the title of the course/s you completed or are enrolled in?

During your training, did you receive any education on how to protect your ears in the sound/music industry?
( ) Yes (please describe)
( ) No

How many years have you worked in the sound/music industry?

On average, how many hours per week do you work in the sound/music industry?

What music genre/s do you mostly work in (select all that apply)
( ) Classical    ( ) House    ( ) Punk    ( ) Country
( ) Jazz    ( ) Rock    ( ) Dub    ( ) Metal
( ) Electronica    ( ) Noise    ( ) Folk    ( ) Pop
( ) Other (please describe)

Thinking about your career in the sound/music industry, please select any or all of the following sound engineering roles that you have performed.
( ) Front of house engineers
( ) System engineer
( ) Monitor mixer
( ) Studio engineer
( ) Other (please describe)

Thinking about your current work in the industry, give a percentage estimate of how your work time is divided between each role. Please make sure your estimates add up to 100%, e.g. system engineer – 80%; front of house – 20%.

How would you describe your work in the sound/music industry?
( ) Employee (full-time)
( ) Employee (part-time)
( ) Freeland/self-employed
( ) Amateur/recreational
( ) Other (please describe)

Has your employer or a client ever provided you with the following? (select all that apply)
( ) Payment to undergo a hearing test
( ) Education or training opportunities related to hearing
( ) Hearing protectors (e.g. earplugs)
( ) None of the above

SOUND LEVELS AND HEARING PROTECTION

Do you believe your hearing is at risk working in the sound/music industry?
( ) Not at all
( ) Maybe a little
( ) Yes, a lot
( ) Not sure
APPENDIX B

Have you taken any steps to protect your hearing? Please describe

Why do you believe your hearing is not at risk?

Which genres do you think pose the greatest risk for hearing damage? (Select as many as apply)
( ) Classical  ( ) House  ( ) Punk
( ) Country  ( ) Jazz  ( ) Rock
( ) Dub  ( ) Metal  ( ) Other (please describe)
( ) Electronica  ( ) Noise  ( ) None of the above
( ) Folk  ( ) Pop

Who do you think is most at risk of hearing damage in a live music setting? (Select all that apply)
( ) Musicians
( ) Venue staff
( ) Sound engineer
( ) Patrons
( ) DJ’s
( ) Other (please describe)

Below is a list showing the individuals you nominated as being most at risk. Please now drag each to the right-hand side in order of most (at the top), to least (at the bottom) at risk. If you only have one selected on your list, simply drag them to the right.

In your opinion, what are the main impediments or barriers to providing safe sound levels in live music venues? (e.g., it might be equipment limitations, attitudes of certain stakeholders, etc.). Please provide as much detail as you can.

What do you think can be done to manage the risk from harmful sound levels in live music venues?

Who do you think is responsible for minimizing the risk from harmful sound levels in live music venues? (Select all that apply)
( ) Venue owner  ( ) DJ’s
( ) Venue management  ( ) Patrons
( ) Sound engineer  ( ) The local council
( ) Artist/musicians  ( ) State workplace health and safety authority
( ) Booking agent  ( ) Music industry peak body
( ) The artists’ management  ( ) Other (please describe)

Below is a list showing the people/organisations you nominated as being responsible for minimizing harmful sound levels. Drag each item to the right-hand list, ranking them from most (at the top) to least responsible (at the bottom). If you only have one person/organization on your list, drag them to the right. [Items piped from previous question]

Have you worn hearing protectors while working in the sound/music industry?
( ) Yes
( ) No
When did you start to use hearing protectors?

<table>
<thead>
<tr>
<th>Option</th>
<th>Time Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Less than 1 year ago</td>
<td></td>
</tr>
<tr>
<td>1 – 5 years ago</td>
<td></td>
</tr>
<tr>
<td>6 – 10 years ago</td>
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<tr>
<td>11 – 15 years ago</td>
<td></td>
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<tr>
<td>16 – 20 years ago</td>
<td></td>
</tr>
<tr>
<td>21 – 25 years ago</td>
<td></td>
</tr>
<tr>
<td>26 – 30 years ago</td>
<td></td>
</tr>
<tr>
<td>more than 30 years ago</td>
<td></td>
</tr>
</tbody>
</table>

Why did you start to use hearing protectors?

What type of hearing protectors have you worn? (Select all that apply)

- Tissue/cotton wool in the ear
- Foam earplugs
- Non-custom, filtered earplugs
- Custom-made earplugs
- Custom-made vented earplugs
- Custom-made electronic earplugs
- Non-custom in-ear monitors
- Custom in-ear monitors
- Other (please describe)

Thinking about your current work in the industry, how often do you wear hearing protectors?

<table>
<thead>
<tr>
<th>Option</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 – 10% of the time</td>
<td></td>
</tr>
<tr>
<td>11 – 20% of the time</td>
<td></td>
</tr>
<tr>
<td>21 – 30% of the time</td>
<td></td>
</tr>
<tr>
<td>31 – 40% of the time</td>
<td></td>
</tr>
<tr>
<td>41 – 50% of the time</td>
<td></td>
</tr>
<tr>
<td>51 – 60% of the time</td>
<td></td>
</tr>
<tr>
<td>61 – 70% of the time</td>
<td></td>
</tr>
<tr>
<td>71 – 80% of the time</td>
<td></td>
</tr>
<tr>
<td>81 – 90% of the time</td>
<td></td>
</tr>
<tr>
<td>91 – 100% of the time</td>
<td></td>
</tr>
</tbody>
</table>

Please describe the work situation(s) and circumstances in which you wear hearing protectors. For example, you might choose to wear different types of hearing protector at an outdoor music festival vs an indoor venue; or you may only wear earplugs for a particular band or genre. Please provide as much detail as you can.

Why do you choose to wear hearing protectors now? (Select all that apply)

- To protect my ears from hearing loss
- To protect my ears from tinnitus
- I have hearing loss and I don’t want it to get worse
- I have tinnitus and I don’t want it to get worse
- To reduce the severity of my hearing-related symptoms after a shift
- My boss requires me to do so
- Other (please describe)

Please describe why (select all that apply).

- I’ve never thought about it before
- I’m not at risk of hearing damage
- The risk of hearing damage is part of the job
- Earplugs are uncomfortable
Earplugs prevent me from being able to do my job
Earplugs are a hassle
Earplugs are too noticeable
Custom-made earplugs are too expensive
Earplugs make it too difficult for me to communicate with others
Other (please describe)

Which of the following would motivate you to wear hearing protectors? (Select all that apply)
If I noticed that my hearing had deteriorated
If I noticed an increase in the severity of my tinnitus
If the severity of my hearing-related symptoms increased after a shift
If my boss required me to
If I found the music was painfully loud
If the music was loud enough that I had to shout to make myself heard
Other (please describe)
None of the above

Have you ever worked in a live music venue where acoustic screens were provided for you?
Yes
No
Unsure

Have you ever worked at a live music venue where earplugs were available for patrons?
No
Yes (earplugs were free or available for purchase)
Unsure

Do you think earplugs should be available to patrons at live music venues?
No, I think it is the responsibility of the patron to bring their own earplugs
Yes, they should be available for free to the patron
Yes, they should be available at a cost to the patron
Unsure

Do you think earplugs should be provided for staff at live music venues, e.g., staff working at the bar, ticket desk, front door etc.?
No, staff should supply their own earplugs
Yes, venues should provide free earplugs for staff
Yes, venues should provide subsidized earplugs for staff
Unsure

Is there anything else you’d like to tell us about your views on hearing in the sound/music industry?
Appendix B-6: Study 4 - Staff Demographic Questionnaire

What are your initials?

What is your age?

Are you:
( ) Female
( ) Male
( ) Indeterminate/intersex/unspecified

What is your job at [insert venue name]?
( ) Bar staff
( ) Sound engineer
( ) Glassie
( ) Door staff
( ) Manager
( ) Security
( ) Other: _________________________

Where do you spend most of your time during a shift?
( ) Behind the bar
( ) On the floor
( ) Sound desk
( ) At ticket desk
( ) Street entrance
( ) Other: _________________________

On average, how many hours/week do you work at [insert venue name]?

How long have you worked here?
( ) <1 year
( ) 1 years
( ) 2 years
( ) 3 years… (options continue until final, below)
( ) > 10 years

How long have you worked at live music venues other than [insert venue name]?
( ) <1 year
( ) 1 years
( ) 2 years
( ) 3 years… (options continue until final, below)
( ) > 10 years

How long have you worked at live music venues other than [insert venue name]?
( ) I haven’t worked at other live music venues
( ) <1 year
( ) 1 years
( ) 2 years
( ) 3 years… (options continue until final, below)
( ) > 10 years
Tinnitus is any sound that a person can hear internally that is not present externally. It may be heard as a buzzing, ringing, whistling, hissing or pulsing sound. Have you ever experienced tinnitus?

<table>
<thead>
<tr>
<th>Never/rarely</th>
<th>Occasionally</th>
<th>Sometimes</th>
<th>Often</th>
<th>Always</th>
</tr>
</thead>
</table>

During or after a work shift have you ever experienced the following symptoms (or an increase in these symptoms)?

- ( ) Ringing in the ears
- ( ) Hearing dullness
- ( ) Blocked sensation in the ears
- ( ) Pain in the ears
- ( ) Sound distortion
- ( ) Other: _____________________________
- ( ) None of these

[If “Ringing in the ears”]

How often have you heard ringing in the ears during or after a work shift?

[If “Hearing dullness”]

How often has your hearing felt dull during or after a shift?

[If “Blocked sensation in the ears”]

How often have your ears felt blocked during or after a shift?

[If “Pain in the ears”]

How often have you felt pain in your ears during or after a shift?

[If “Sound distortion”]

How often has your hearing been distorted during or after a shift?

How often have you worn hearing protection during a shift at [insert venue name]?  

<table>
<thead>
<tr>
<th>Never/rarely</th>
<th>Occasionally</th>
<th>Sometimes</th>
<th>Often</th>
<th>Always</th>
</tr>
</thead>
</table>

What type of hearing protectors have you worn during a shift at [insert venue name]?  

- ( ) Foam/disposable earplugs
- ( ) One-size-fits-all filtered earplugs
- ( ) Custom-made earplugs
- ( ) In-ear-monitors
- ( ) Other (Please describe)
- ( ) None of these

To the best of your knowledge, which of the following are available to staff at [insert venue name]?

- ( ) Foam/disposable earplugs
- ( ) one-size-fits all filtered earplugs
- ( ) Custom-made earplugs
- ( ) Breaks away from loud areas
- ( ) Rotation between quiet and loud work areas
- ( ) Shorter shifts when loud
- ( ) Sound barriers around work areas
- ( ) Annual hearing tests
( ) Training about noise and hearing
( ) None of the above

**Which of the following would you like to see available to staff?**
( ) Foam/disposable earplugs
( ) one-size-fits all filtered earplugs
( ) Custom-made earplugs
( ) Breaks away from loud areas
( ) Rotation between quiet and loud work areas
( ) Shorter shifts when loud
( ) Sound barriers around work areas
( ) Annual hearing tests
( ) Training about noise and hearing
( ) None of the above

**Is there anything else you’d like to add before we go?**
Appendix B-7: Study 4 - Staff Sound Level Questionnaire

What are your initials?

What is your age?

Are you:
( ) Female
( ) Male
( ) Indeterminate/intersex/unspecified

What do you think about the sound level tonight?

Much too quiet  A little too quiet  Just right  A little too loud  Much too loud

Look at the scale below and use the slider to indicate the sound level tonight.

Conversation is . . .

0 5 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80 85 90 95 100

If you could control the sound level, what would you prefer it to be?

How satisfied are you with the sound level tonight?

Very Dissatisfied  Dissatisfied  Neutral  Satisfied  Very Satisfied
Appendix B-8: Patron Sound Level Questionnaire

What is your age?

Are you:
( ) Female
( ) Male
( ) Indeterminate/intersex/unspecified

How often do you go to live music venues?
( ) Never
( ) Once or twice a year
( ) Once every 2-3 months
( ) Once a month
( ) Once a fortnight
( ) Once a week
( ) More than once a week

Have you experienced any of the following during or after a visit to a live music venue? (Select all that apply)
( ) Tinnitus/ringing in the ears
( ) Ears feel blocked
( ) Ears feel dull
( ) Sound distortion
( ) Not being able to hear as well the next day
( ) None of the above

Have you worn hearing protection at a live music venue?
Never/rarely  Occasionally  Sometimes  Often  Always

What do you think about the sound level tonight?
Much too quiet   A little too quiet   Just right   A little too loud   Much too loud

Using the scale below, move the slider to indicate the sound level tonight.

Conversation is . . .

If you could control the sound level, what would you prefer it to be?
How satisfied are you with the musical experience tonight?
How many standard drinks have you had tonight?
Appendix C: The Musician Oriented Scale of Improvement

### Listening Situations

<table>
<thead>
<tr>
<th>Number in order of priority</th>
<th>Follow-up *</th>
</tr>
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<tbody>
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*At the follow-up appointment record the proportion of time plugs/devices/strategies have been employed listening situation.

### Hearing Protection Goals

<table>
<thead>
<tr>
<th>Number in order of priority</th>
<th>Follow-up **</th>
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</thead>
<tbody>
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</table>

**At the follow-up appointment record the extent to which Hearing Protection Goals have been addressed using this scale.
Not at all: 0; Partially: 1; Mostly: 2; Completely: 3; Exceeded: 4.

### Comments

<table>
<thead>
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<th>Comments</th>
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</table>

Client:__________________________  Goals set:______________  Follow-up:______________

Audiologist:_________________  Hearing Protection:______________

Please select the dates from the drop-down calendar on the right.
Appendix D: Investigating the Use of Sound Level Management Software in Live Indoor Music Venues

The following paper, incorporated in its entirety, presents the pilot results presented by Dr Johannes Mulder at the International Conference on Music-Induced Hearing Disorders, June 2018:

Published conference paper


Aim: To investigate if access to sound-level management software, 10EaZy, with implementation of a 15-minute maximum LAeq sound level, would result in lowered sound exposure of patrons and staff. This paper focuses on preliminary data from one of six venues and presents initial findings from this study.
ABSTRACT

As part of a larger study of sound (pressure) levels in small and midsized live music venues, the effect of using sound level management software (10EaZy), on sound exposure levels of patrons and staff was investigated. Overall, no reduction in sound level exposure was observed, however, results suggest that use of 10EaZy led to significantly less time spent at higher volumes as measured for loud performances.
Introduction

Music-induced hearing injury (MIHI) is a preventable, yet prevalent form of injury caused by cumulative over-exposure to sound affecting both musicians and the listening public (Zhao et al., 2010). Symptoms commonly reported by exposed musicians include hearing loss, tinnitus, distortion and reduced sound tolerance (Kahari et al., 2003; Laitinen & Poulsen, 2008; Patel, 2008; El Dib et al., 2008). MIHI typically presents as a symmetrical sensorineural loss with a characteristic ‘notch’ centred on 4kHz, caused by the mechanical and metabolic destruction of fine inner ear structures (Nordman et al., 2000). Temporary threshold shifts (TTS), can also occur immediately post-exposure, subjectively improving over 24-48 hours, yet increasing the risk of permanent damage and secondary symptoms, such as tinnitus and sound sensitivity (Nordman et al. 2000; Laitinen & Poulsen, 2008; Furman et al., 2013). Beyond this, MIHI can lead to functional changes, including decreased ability to discriminate speech in noise, impaired frequency resolution, and psychological symptoms of depression or social isolation (Mohamad et al., 2016; Eggermont 2017).

Despite the risks, the use of hearing protection to counter the potential harmful effects of excessive exposure to live music remains low. In a survey of over 9000 participants, 61% had experienced tinnitus or hearing impairment after a concert, yet only 14% had used earplugs in a place of live music. Furthermore, up to half of concert attendees reported they would view their peers negatively if they used hearing protectors, evidence that there is a degree of stigma associated with protective behaviours in music (Chung et al. 2005). Staff use of hearing protectors in music venues is also low, with issues such as, comfort, discretion and distortion of speech and music commonly cited (Kelly et al., 2015; Jamieson, 2015).

At present, the best parameters we have for estimating the potential for hearing risk in music venues are derived from occupational health and safety standards. In Australia, these guidelines outline a daily noise dose of 85 dB L$_{Aeq}$ for 8-h, and 140 L$_{Cpeak}$, with exposure time halved for every doubling of intensity (3dB). Standards Australia 2005). This means 8 hours at 85 dB L$_{Aeq}$ carries the same risk as 88 dB L$_{Aeq}$ for 4-h, or 91 dB L$_{Aeq}$ for 2-h. By these standards, sound levels in music venues regularly exceed those deemed to be safe, with volumes of 100 dBA not uncommon (Goggin et al., 2008; Beach et al., 2013) To better manage the risks, several countries have introduced legislation which impose limits on the maximum sound levels permissible in music venues (Tronstad & Gelderblom, 2016).

10EaZy is a sound level management software system, designed to help venues and sound engineers adhere to sound level regulations. It does this by translating the time trade-off for high sound levels into a novel metaphor, known as ‘decibel-banking’ (Navne, 2015; for an in-depth description see Mulder, 2016). The interface displays each decibel above the target level in red, and each decibel below in green, continually informing the user as to how many decibels are ‘left in the bank’ as they aim for the set L$_{Aeq}$, 15min target.

Systems like 10EaZy are commonly used for sound level management in music festivals and concerts, but at the time of this study, only anecdotal evidence for the efficacy of such a system in an indoor live music venue was available. The data reported here is part of a larger study examining the typical sound levels and hearing health of patrons and staff at indoor music venues. As a whole, the hypothesis was that access to the 10EaZy system, and implementation of a 15-minute maximum L$_{Aeq}$ sound level, would result in lowered sound exposure of patrons and staff. Patrons were also canvassed as to their perceptions of any such change. This paper focuses on preliminary data from one of six venues, and presents initial findings from this study.

2 Methods

This study was conducted under the ethics approval and oversight of the Royal Victorian Eye & Ear Hospital’s Human Research Ethics Committee (project number 15/1225H).
Participants
Invitations to participate were emailed to seven small-to-medium sized live music venues within the Melbourne metropolitan area, and six agreed to participate. Data pertaining to one venue only were ready for analysis and these are reported here. A total of 61 patrons at the venue participated in the study (male = 30, female = 27, indeterminate = 4), ranging in age from 19 to 58 years ($M = 28.9, SD = 10.0$). Six staff members at the venue also participated (male = 1, female = 5), ranging in age from 22 to 35 years ($M = 27.7, SD = 4.9$).

Materials
A Class 2 recording system with a Dell Inspiron laptop (Regulatory Model P25T), pre-amp and MK216 microphone was installed in the venue, using Version 2.6 of 10EaZy (SG Software, Denmark; AS IEC 61672-1-2004). The set-up was placed at the sound desk, with the microphone left in a fixed location throughout the study, secured at ear level to the sound engineer. A log sheet for tracking band performance data and information on the mixing engineer was also supplied. Five calibrated Casella dBadge (CEL-350) noise dosimeters were used to measure $L_{Aeq}$ and $L_{Cpeak}$ sound levels.

Surveys
Two surveys were designed for this study using online survey platform SurveyGizmo (SurveyGizmo, Boulder, Colorado). One survey was for staff and the other for patrons. The patron survey consisted of 10 closed items, covering hearing health and hearing protection use in a live-music setting, as well as patrons’ satisfaction with the venue’s sound levels. The staff survey covered the topics of hearing health and hearing protection use, as well as listening wants and needs in a live-music workplace. Neither patrons, nor staff were incentivised or rewarded for their time completing these surveys. Responses were recorded anonymously, and as such, signed consent was not required.

Procedure
At initial contact, a statement outlining the study was supplied to the venue. This was followed up by an in-person meeting to discuss implementation of the protocol in the venue. Informed consent was obtained from the venue manager, with authority to sign on the venue’s behalf. Once the study had been agreed upon, the staff survey was emailed to the manager to pass onto all available staff to complete. No inducements or rewards were offered for participation; however, the venue was provided with the sound level measurements at the completion of the study.

The study was conducted in two phases. During Phase A, for each live music performance, the venue was asked to log the name, genre and performance time of each band, including if the mixer was an in-house or guest engineer. The venue was instructed to have the 10EaZy system recording for the duration of each performance, excluding DJ sets. The laptop screen was to be kept out of sight of the engineer in this phase, so as not to influence their management of the sound levels. The time weighting on the 10Eazy system was set to ‘fast’, and it logged sound levels at intervals of one minute ($L_{Aeq1min}$), 15 minutes ($L_{Aeq15min}$) and 60 minutes ($L_{Aeq60min}$). At the close of the system, an automated email was sent to the researchers, containing the night’s sound level log data and an audio recording of the night’s performance.

At the completion of Phase A, a report was sent to the venue outlining the sound levels recorded in their venue, along with instructions on how to use 10Eazy in Phase B. They were asked to discuss the Phase A measurements with their team and report back with a desired $L_{Aeq15min}$ to use in Phase B. Once set, Phase B commenced. The venue was re-instructed to use 10Eazy for each live music performance. This time, however, the laptop was positioned in view of the sound engineer, and they were encouraged to interact with the ‘Maximum Average Manager’ (MAM) of the system. The MAM provided the sound engineer with minute-by-minute updates of the venue’s sound levels, and how they compared to the target level, as set by the venue, thus updating them constantly on their

1 The lack of backline sources (i.e. guitar amplifiers and drum sets) set DJ performances apart in terms of sound level management).
‘decibel bank’ or ‘headroom’. At the close of the system, venue management and the head sound engineer also received an email summary of the night’s audio.

Dosimeter recordings were measured twice during the study: on the final night of each phase. The recordings were taken at five fixed locations; the sound desk, the ticket desk, the bar, on stage and central to the dancefloor (hung from the lighting rig roughly three metres above ground). The other dosimeters were placed as close to head height as possible, working within the allowable space and structure of the venue, avoiding any physical obstructions between dosimeters and speakers. Patrons were approached during these ‘dosimetry nights’ to participate in the sound level survey. Patrons were only engaged between performances, so as not to interfere with their musical experience.

Data Management and Analysis
To maintain consistency across the sound data, daytime recordings and any involving computer failure (and thus corrupt or incomplete data) were excluded. Furthermore, any sound captured prior to the onset of live music (i.e. the first band) and after the final performance was excluded. This resulted in the omission of five live-recording sessions, leaving a total of 4865 minutes of sound data captured over 27 nights in Phase A, and 3580 minutes over 21 nights in Phase B.

Descriptive statistics were used to analyse responses to the survey data. For between-phase comparisons, independent tests and analysis of variance were performed. A significance threshold of .05 was set for all analyses. Due to the small sample size, all patrons identifying as indeterminate were excluded from post-hoc analyses involving gender as an independent variable. For investigations involving age as a parameter, patrons were divided into two categories by the sample mean; adult (≥28 years) and young adult (≥27 years).

3 Results

Patron Hearing Health

Of the 61 patrons, 33 were surveyed in Phase A (male = 16, female = 13, indeterminate = 4), ranging from 20 to 58 years (M = 31.0, SD = 10.7), and 28 in Phase B (male = 14, female = 14), ranging from 19 to 56 years (M = 26.4, SD = 8.8).

Patrons were asked if they had experienced any of the following symptoms of hearing injury, either during, or directly after visit to a live music venue (see table 1). Tinnitus was the most commonly reported (57.4%; n = 35), followed by hearing dullness (26.2%; n = 16) and ‘not being able to hear as well the next day’ (18%; n = 11). Hearing distortion and a sensation of blocked ears were both reported by 9.8% (n = 6), while 32.8% (n = 20) reported they had not experienced any of the above symptoms.

Table 1. The proportion of patrons and staff who had experienced hearing symptoms during or after attendance at a live music venue.

<table>
<thead>
<tr>
<th>Symptom</th>
<th>Patrons</th>
<th>Staff</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tinnitus</td>
<td>57.4%</td>
<td>16.7%</td>
</tr>
<tr>
<td>Dullness</td>
<td>26.2%</td>
<td>16.7%</td>
</tr>
<tr>
<td>Distortion</td>
<td>9.8%</td>
<td>16.7%</td>
</tr>
<tr>
<td>Pain</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Blocked Ears</td>
<td>9.8%</td>
<td>33.3%</td>
</tr>
<tr>
<td>Reduced Hearing</td>
<td>18.0%</td>
<td>*</td>
</tr>
</tbody>
</table>

*Question not asked in staff survey

Attendance at live music venues was high, with 34.4% (n = 21) of patrons attending at least once a fortnight, 32.8% (n = 20) on average once per month and 24.6% (n = 15) at least once every 2-3 months. A small percentage of surveyed patrons attended music venues less than twice per year (8.2%; n = 5). Hearing protection use was low, with 75.4% (n = 46) reporting that they rarely or never used protectors in a live music setting. Nine individuals had used them occasionally or sometimes (14.7%), with the remaining 9.8% (n = 6) reported wearing them often or always. Using Fishers exact test, frequency of live music attendance was found not to be related to the use of hearing protection, p = .34. A Pearson chi-square test found age (p = .20) was also unrelated, while gender was close to significance (p = .08), with females more likely to report never or rarely
wearing hearing (88.9%, n = 24) compared to (70%, n = 21).

**Patron Satisfaction**

Using a five-point Likert scale, patrons were asked to rate their satisfaction with the musical experience, ranging from very dissatisfied to very satisfied. Overall, patrons responded positively, with 93.4% (n = 57) being satisfied or very satisfied. Only one individual was very dissatisfied with their experience at the venue (1.6%) and 3 remained neutral, (4.9%) all of which were interviewed during Phase A. Using a two-sided Fisher’s Exact test, no significant difference was observed between satisfied (satisfied or very satisfied) patrons in Phase A (87.9%, n = 29) and those in Phase B (100%, n = 28), p = .08. The same analysis found age (p = .16) and sex (p = .35) to be unrelated to patron satisfaction.

As above, a 5-point Likert scale was used by patrons to rate their attitude towards the sound levels in the music venue, ranging from much too quiet to much too loud. During both phases, the majority felt the sound levels were just right in the venue (73.8%, n = 45). Four reported them as either much too quiet or a little too quiet (6.6%), while 21.3% found the sound to be a little too loud (n = 13). No patrons reported the volume as being much too loud. Pearson Chi-square analysis found phase (p = .17), age (p = .67) and sex (p = .46) to be unrelated to patron perception of the sound levels.

**Staff Hearing Health**

Staff were asked if, and to what degree, they had experienced tinnitus daily. Half the respondents reported hearing it sometimes (n = 3), and the remainder often or always. They were then asked which hearing injury symptoms they had experienced either during or after a work shift. Three reported no post-shift symptoms. Among the other three respondents, the most common of these was a sensation of blocked ears (n = 2), followed by tinnitus, hearing dullness and distortion, each reported by 1 person. No participants reported experiencing pain.

**Staff Hearing Protection**

Use of hearing protection by staff was low, with 4 never/rarely using them, and the remaining 2 staff using them occasionally. Two had used foam earplugs, and 1 individual had used filtered non-custom plugs. A further comment was made by one staff member that they had used a security communication earpiece as a form of hearing protection.

**Sound Measurements**

At the start of Phase B, the venue nominated to set the 10EAzy system at 102 LAeq,15min. By the end of the first week, however, this limit had been reduced to 98, following feedback from the venue’s sound engineer that it was too high. It remained at this level for the rest of Phase B.

The sound level for each gig was calculated using the LAeq,15min 10EAzy recordings from the start of the first band, to the end of the headline’s performance (see Figures 1 and 2). Four evenings in Phase A were excluded as outliers, because they featured small folk bands or solo instrumentalists, and therefore recorded significantly lower sound levels compared to the other gigs (see black data points on Figure 1). This left 23 nights of recording in Phase A, and 21 nights in Phase B.

Across both phases, the mean sound level was 93 dB (SD = 2.6), with the minimum, 88 dB, recorded on a Tuesday night in Phase B, featuring a line-up of indie-pop, and the maximum, 98 dB, recorded on a Monday night in Phase A, featuring four Punk bands. In Phase A the mean sound level was 93 dB (SD = 2.73), and 94 dB in Phase B (SD = 2.32). A three-way analysis of variance was performed investigating the effect of the day of the week, (weekend [Friday/Saturday] or weekday), engine (guest, in-house, a mixture of both) and phase (A or B). There was a significant main effect of engineered, F(2,33) = 3.40, p < .05, with the mean LAeq for in-house engineers (M = 95, SD = 2.65), louder than guest (M = 93, SD = 2.32) or a mixture of both (M = 93, SD = 2.83). Phase also yielded a significant effect, F(1,33) = 4.41, p < .05, with sound levels in Phase A (M = 93, SD = 2.73) softer than Phase B (M = 94, SD = 2.32). No significant effect of day of the week was noted, F(1,33) = 1.38, p = .25.
highest were recorded on the dance-floor, with the equivalent of 990% of a daily noise dose in Phase A, and 1381% in Phase B. These results were comparable with the sound levels recorded by the 10EaZy system, which measured an \( L_{Aeq} \) of 95 and 96 at the sound desk for each phase, respectively.

Table 2. Dosimeter recorded sound levels and exposure by location

<table>
<thead>
<tr>
<th>Location</th>
<th>Phase A</th>
<th>Phase B</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stage</td>
<td>103 (300%)</td>
<td>103 (200%)</td>
</tr>
<tr>
<td>Dance floor</td>
<td>99 (100%)</td>
<td>100 (100%)</td>
</tr>
<tr>
<td>Bar</td>
<td>96 (100%)</td>
<td>97 (100%)</td>
</tr>
<tr>
<td>Sound desk</td>
<td>93 (100%)</td>
<td>96 (100%)</td>
</tr>
<tr>
<td>Ticket desk</td>
<td>88 (90%)</td>
<td>87 (90%)</td>
</tr>
</tbody>
</table>

Note: Percentage values show the daily noise exposure dose (rounded) as calculated per Australian occupational noise management standards (Standards Australia, 2005).

**Punk vs Metal**

To more closely examine the impact of 10EaZy on mixing behaviour during particularly loud performances, the loudest nights from each phase were selected for analysis. These consisted of a punk night in Phase A, with an \( L_{Aeq} \) of 98, and a death metal night in Phase B, \( L_{Aeq} \) of 97. The \( L_{eq} \) values over the course of each gig can be seen in Figures 3 and 4.

An estimation of the data as it would have been seen by the sound engineer using the MAM of the 10EaZy system, was derived for each \( L_{eq,1min} \) recording. The \( L_{eq,1min} \) value was subtracted from the nominated target of 98 \( \pm 6\) dB, for clarity all recordings outside 98 \( \pm 6\) dB were excluded, mirroring the restriction of the MAM interface.
showing at most 6 red or green boxes each representing 1 dB. We noted however that there were no $L_{eq1min}$ values over 104 dB recorded at this venue.

Figure 4. Sound levels recorded on a metal line-up in Phase B

The plot of these derived MAM readings can be seen in Figures 5 and 6, showing the progression of cues the sound engineer would have received during the evening, with red (positive) values being above the target, and green (negative) at or below. In Phase A, the average MAM reading was -1.4 ($SD = 3.4$), and .08 ($SD = 1.9$) in Phase B. An independent t-test revealed the mean of the $L_{eq1min}$ values greater than 98 was significantly higher in Phase A ($M = 101.7$; $SD = 1.3$) than in Phase B ($M = 99.3$; $SD = 1.0$), $t(146) = 12.4, p < .05$. Using $L_{eq1min}$ recordings, time spent at or above the 10EaZy target of 98 dB was then compared between phases. A two-proportions z-test found there to be a significant difference, with 75% of $L_{eq1min}$ values ≥ 98 in Phase A, compared to only 49% in Phase B, $z = 5.2, p < .01$.

Figure 5. MAM readings during a punk line-up in Phase A

Figure 6. MAM readings during a metal line-up in Phase B

4 Discussion

The data presented in this paper confirms that patrons and staff in live music venues may be at risk of hearing injury due to high levels of sound exposure. The sound levels recorded on 44 evening performances ranged between 88 and 98 dB $L_{Aeq}$, averaging 93 dB $L_{Aeq}$ across the study period. Two-thirds of patrons (67%) reported experiencing a symptom of hearing injury during or after a gig, most commonly tinnitus, which was or had been experienced by 57% at least once after a show. Tinnitus rates were also found to be high amongst venue staff members – all six reported incidences of tinnitus at least sometimes, and for three employees, it was frequent or constant. These findings are consistent with previous research indicating higher rates of tinnitus in individuals with significant music-related exposures (Beach et al., 2010; Putter-Katz et al., 2015; Guilliver et al., 2015 Williams & Carter, 2017).

Despite the prevalence of symptoms of hearing injury, the use of hearing protection in the sample was low. In patrons, 75% had never or rarely used earplugs in a live music venue, a figure consistent with earlier studies (Bogoeh et al., 2005, Cha et al., 2015). For staff, only two out of the six staff reported wearing earplugs exceptionally during a shift. The reasons behind low earplug use were not explored in this study, however the literature suggests that issues relating to sound quality, comfort, and lack of awareness surrounding the
health injury risks are commonly cited in the music industry (Goggin et al., 2008; Beach et al., 2010; Kelly et al., 2015; Jamieson, 2015).

At first glance, the sound level data from this paper suggest that use of 10EaZy in this setting led to a greater sound exposure for patrons and staff because there was an increase in sound level between phases. In Phase B, the average was 94 dB $L_{Aeq}$ when the 10EaZy was in use, compared to 93 dB $L_{Aeq}$ when it was not (Phase A). However, it should be noted that despite the statistical significance of this result, a 1-dB difference falls within the tolerance limits of the class 2 measurement system (Standards Australia, 2004) and therefore caution should be used when interpreting this result. The more detailed analysis of the two loudest gigs from each phase showed that the 10EaZy system appeared to have the opposite effect; with significantly less time spent above 98 dB in Phase B, than in Phase A. This could indicate the benefit of the MAM feature, in assisting the sound engineer in maintaining safe sound levels during particularly during louder performances. This finding will be explored further when we complete the analysis of the full dataset from all six venues.

Further, the sound levels measured at the venue in Phase A presented here, are somewhat lower than those reported in recent studies (Goggin et al 2008; WHO 2015). As can be seen from Figure 1, sound levels varied widely for each night, suggesting that the sound staff at this venue were able to assess and accurately control the desired sound level for each night, depending on line-up and audience size. In Phase B, the data reveal a more consistent approach to sound levels, with more than one-third of gigs within 3 dB of the 98 dB target level, potentially as a consequence of the 10EaZy system. This could suggest that the sound staff in this venue approached the limit set in 10EaZy as a ‘target’ rather than as a ‘limit’. Therefore, in this particular venue, the limit could have been set to a lower level, e.g. $L_{Aeq15\text{min}}=96\text{dB}$, which would make it significantly lower than the upper limits cited in different European regulations and covenants, such as France (102 dB $L_{Aeq15\text{min}}$) or The Netherlands (103 dB $L_{Aeq15\text{min}}$). Additionally, the effect of using the ‘limit’ as a ‘target’ indicates that the instructions with regard to using 10EaZy given at the start of phase B needed to be more specific.

As noted, the data reported in this study are part of a larger investigation of six live music venues, and analysis of the entire data set may give an insight into whether the between-phase differences will be observed in a range of different venues, or if the venue discussed in this paper is an outlier in terms of staffing, acoustics and programming.

5 Conclusions

The data presented in this paper suggest that patrons and staff in live music venues are at risk of long-term hearing injury caused by exposure to music, and that more work is needed to promote the uptake of healthy hearing behaviours in the industry. Use of a monitoring system, such as 10EaZy, did assist with management of high sound levels, particularly in gigs where loud levels of music were expected. However, a single “systems-based” approach may not be fully effective for indoor venues in which sound levels vary considerably between different nights and bands. For these environments, greater flexibility in setting the target level may be required.

References


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