Commentary

Applying the Hierarchy of Hazard Control to Regulation of Sound Levels in Entertainment Venues

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Abstract

Excessive sound levels at events where amplified music is a central element pose a risk to hearing. Whereas noise exposure in the workplace has been recognized as a hazard for over a century, the potential harm resulting from recreational sound exposure has only become apparent in recent years. In occupational settings where sound levels are high, employers are required to implement risk-mitigation strategies to reduce sound exposure and protect employees in accordance with the hierarchy of controls. In principle, this same risk management approach can be applied to entertainment venues. In this paper we discuss how the measures stipulated in various policies and regulations aimed at protecting the hearing of audience members at entertainment venues fit within the hierarchy of controls. We compare the relative likely effectiveness of each of the measures and outline how the particular characteristics of entertainment venues impact on the practical application of these measures.

Keywords: noise; noise and leisure; risk management

Introduction

Attending events where amplified music is a central element, such as concert arenas, nightclubs and music venues, is a pleasurable leisure activity, enjoyed by thousands of people on any given day. Like many recreational pursuits, consumption of loud music involves both

rewards and risks (Blessner, 2007; Welch and Fremaux, 2017a). As sound levels increase, the risk to hearing also increases and the potential harm posed by this hazard has become the subject of scientific research over the past several decades (Hanson and Fearn, 1975; Meyer-Bisch, 1996; Kraaijenga *et al.*, 2018). In the workplace, where

noise exposure has been recognized as a hazard for over a century, risk managers implement risk-mitigation strategies in accordance with the hierarchy of controls. These range from elimination, which is considered most effective, to the use of personal protective equipment—the least effective strategy (Boyle, 2008; Fig. 1).

In principle, this same risk management approach can be applied to entertainment venues to minimize the risks to attendees' hearing associated with loud sound levels. Controls may include provision of earplugs (personal protective equipment); restricting access to loudspeakers (engineering controls) through to substitution of the risk by implementing active noise control at the source. Although individual music venues may elect to implement some or all of these measures, in order to effect systemic change, ideally, the measures would be implemented through policies and guidelines, regulation, or legislation.

The purpose of this paper is to discuss how the measures set out in current policies and regulations in countries across the world to protect the hearing of audience members within entertainment venues fit within the hierarchy of controls as a way of assessing their likely effectiveness. A number of European countries have introduced detailed regulations and policies in this regard, likely influenced by the noise exposure limits set out in the European Directive 2003/10/EC (European Parliament and Council, 2003). Some other countries, such as Mexico, USA, Nicaragua and Trinidad and Tobago also have regulations relating to sound levels in entertainment venues but these are less detailed than those in place in Europe. See Table 1.

Figure 1. Hierarchy of controls (adapted from NIOSH, <https://www.cdc.gov/niosh/topics/hierarchy/default.html>).

A review of the regulations shows that they commonly include the following measures:

- A sound level limit
- Real-time sound level monitoring
- Provision of warnings—at the venue and on tickets and marketing materials
- Provision of earplugs—free or at low cost
- Ensuring attendees can access quiet zones or rest areas
- Restricting audience access to loudspeakers

This suite of six measures includes methods that range from most to least effective within the hierarchy of hazard controls. See Fig. 2. Elimination and substitution are regarded as the most effective strategies, and while elimination of the hazard (loud music) is not feasible in this context, long periods of high-intensity sound can be substituted with sound of lower intensity and/or shorter duration. Warnings are classified as an administrative control, whereas restricting access to speakers and providing rest areas are engineering controls, in which people are isolated from the hazard. Finally, provision of earplugs is consistent with the method of control that is regarded as least effective: use of personal protective equipment.

A set of measures such as these would strike a balance between a regulatory top-down approach and a more autonomous bottom-up approach. On the one hand, policymakers, knowing the risks involved, have a duty of care to act to limit sound levels in order to reduce the risk to attendees' hearing at entertainment venues (especially considering that many attendees may be unaware of the potential for harm). On the other hand, one could argue that audience members should take responsibility

Figure 2. Recommended hierarchy of controls for entertainment venues.

Table 1. Guidelines, regulations, and legislation that aim to protect attendees' hearing in entertainment venues—sound level limits (T = duration of event).

Country/region/ city/state	Reference	Specified sound level limits			Other protective measures				
		Upper limit	Additional limit	Peak limit	Lower limit for <18 years	Provide warnings	Display level to operator/ audience	Retain sound level protection data	Provide access to rest speakers area
Switzerland ^a	Cercle Bruit (2018), Swiss Confederation (2012)	100 dB L _{Aeq,60min}		<125 dB L _{r,fast}	✓	✓	✓	✓	✓
Netherlands ^b	Vereniging Nederlandse Poppodia en Festivals <i>et al.</i> (2018)	103 dB L _{Aeq,15min}		<140 dB L _{Cpeak}	✓	✓	✓	✓	✓
Belgium—Flanders ^a	Departement Leefmilieu Natuur en Energie (2016), Flemish Government (2013)	100 dB L _{Aeq,60min}	102 dB L _{Aeq,15min}			✓	✓	✓	✓
Belgium—Brussels ^a	Government of the Brussels-Capital Region (2017), Leefmilieu Brussel (2017)	100 dB L _{Aeq,60min}	102 dB L _{Aeq,15min}			✓	✓	✓	✓
Germany ^b	Deutsches Institut für Normung (2007)	99 dB L _{Aeq,30min}		<135 dB L _{Cpeak}		✓	✓	✓	✓
France ^a	République Française (2017)	102 dB L _{Aeq,15min}	118 dB L _{Ceq,15min}		✓	✓	✓	✓	✓
Norway ^b	Norway (2011)	99 dB L _{Aeq,30min}				✓	✓	✓	✓
Austria ^a	Republic of Austria (2011)	100 dB L _{Aeq,1min}		<130 dB L _{Cpeak}		✓	✓	✓	✓
Sweden ^a	Sweden (2005)	100 dB L _{Aeq,T}	115 dB L _{Afmax}		✓	✓	✓	✓	✓
Czech Republic ^a	Czech Republic (2011)	100 dB L _{Aeq,4h}	102 dB L _{Smax}						
Italy ^a	Agenzia Nazionale per la Protezione dell'Ambiente (2001), Presidente del Consiglio dei Ministri (1999)	95 dB L _{Aeq}							
United Kingdom ^b	Health and Safety Executive	107 dB L _{Aeq,T}		<140 dB L _{Cpeak}		✓			✓
Mexico ^a	United Mexican States (2013)	100 dB L _{A,4h}							
Nicaragua ^a	Republic of Nicaragua (2005)	110 dB L _{Amax}							
Delaware—USA ^a	State of Delaware (1982)					✓			
Minneapolis—USA ^a	City of Minneapolis (2014)								
San Francisco—USA ^a	City and County of San Francisco (2002)								
Trinidad and Tobago ^a	Republic of Trinidad and Tobago (2000)					✓			

^aLegally binding documents, i.e. laws, decrees, codes, regulations, or ordinances issued at the federal, state, or local level.^bNon-legally binding documents, i.e. recommendations, standards, or covenants.

for their hearing health and wellbeing. Under the model proposed here, the mandated sound level limit would act to control the risk level, but at the same time, audience members would be informed of the potential risks via appropriate warnings. This will enable them to make an informed decision about how to manage their own sound exposure and when to take protective action, such as using earplugs or taking breaks in quiet zones. The rationale for including each of the recommended elements is described below.

Substitution

Sound level limits

Deciding on an appropriate evidence-based sound level limit as a substitute for the high-intensity sound levels typically found in entertainment venues is not straightforward. In the workplace, the daily exposure limit is typically 85 dB $L_{Aeq,8h}$ with a 3-dB exchange rate (NIOSH, 1998), which means that when the sound level increases by 3 dB, exposure time must be halved to maintain the equivalent level of risk. In recreational settings, there is debate as to whether this criterion should be used, with some authors questioning whether or not musical and industrial exposures have an equivalent impact on hearing (Lindgren and Axelsson, 1983; Strasser *et al.*, 2003). Another complicating issue is duration of exposure. Unlike the workplace, where workers' exposure periods are relatively predictable and regular and damage-risk criteria can be formulated on this basis, audience members' attendance at entertainment venues is unpredictable, irregular, and highly variable between individuals. Neitzel and Fligor (2017) considered both of these issues and suggested that 83 dB $L_{Aeq,8h}$ would be an appropriate recreational exposure. (Under the equal-energy principle, this is equivalent to 86 dB $L_{Aeq,4h}$ or 89 dB $L_{Aeq,2h}$.) This recommendation assumes that musical and industrial sound are equally impactful and takes into account that lifetime recreational sound exposure begins in childhood, and therefore extends beyond the 40-year exposure period assumed in workplace damage-risk criteria. The authors argued that 83 dB $L_{Aeq,8h}$ would be sufficiently protective of the vast majority of people, and yet it is a great deal lower than typical sound levels found in music venues, and unlikely to be accepted as a sound level limit by the music industry.

The review of the various European sound level limits presented in Table 1 suggests an upper level of around 100 dB L_{Aeq} is more likely to be accepted by the music industry. This figure is consistent with sound levels that are likely to meet the socio-cultural expectations of audiences and performers (Parnell and Hartcher, 2017; Welch and Fremaux, 2017b). Importantly, such a level

would also meet the preference of many audience members who research has repeatedly shown would prefer sound levels that are lower than the very high-intensity levels often encountered in nightclubs and live music venues (Mercier and Hohmann, 2002; Gilles *et al.*, 2014; Johnson *et al.*, 2014; Beach and Gilliver, 2019).

It is important to note that setting a sound level limit of 100 dB L_{Aeq} does not constitute a declaration that this is 'safe'. Rather, regulations should include a statement advising that the prescribed level should not be considered 'safe', and that risk to an individual's hearing will vary according to the time an individual spends in a venue and the amount of exposure that one receives from other sources. For example, the Dutch covenant (Vereniging Nederlandse Poppodia en Festivals *et al.*, 2018) that sets out guidelines for the music industry in the Netherlands states:

Translation: 'The parties to the agreement realize that the [prescribed] noise levels...are not absolutely safe for every individual. Hearing damage can occur under the recommended sound level... Therefore, the parties to the covenant regard it as important to inform visitors and professionals how to reduce the risk of hearing damage.' page 6

Requiring that venues substitute current levels with lower sound level limits that do not exceed 100 dB L_{Aeq} would at the very least reduce the prevalence of loud music events that exceed this level. As sound levels increase, the risk of hearing damage increases exponentially and when the sound level exceeds 100 dB L_{Aeq} the exposure values escalate quickly. For example, at 100 dB L_{Aeq} , a 4-h event is equivalent to 16 Pa² h; at 103 dB L_{Aeq} exposure increases to 32 Pa² h; at 106 dB L_{Aeq} , it's 64 Pa² h; and at 109 dB L_{Aeq} , exposure reaches 128 Pa² h. Setting a limit of around 100 dB L_{Aeq} will not prevent the risk of harm but it would almost certainly reduce the risk of harm.

There is a risk that setting a sound level limit of 100 dB L_{Aeq} will result in a 'drift' towards this level, including events that were previously below 100 dB L_{Aeq} . There is some evidence of this in preliminary data presented by McGinnity *et al.* (2018) in which a sound level limit of 98 dB L_{Aeq} was introduced to a music venue. During the evaluation period, there was less variation in the sound levels compared to the period before the limit was introduced and most events fell within 3 dB of the 98 dB L_{Aeq} level, suggesting that the venue sound engineers may have subconsciously treated it as a 'target' rather than a limit.

One solution may be to implement a staged approach to sound levels as a way of encouraging a variety of sound levels across events. In the German standard, for example, there is an upper limit of 99 dB L_{Aeq} but a lower limit of 95 dB L_{Aeq} (with less onerous concomitant requirements) is also provided (Deutsches Institut für Normung, 2007).

Real-time sound level monitoring

It is essential that lower sound levels are verified using real-time sound level monitoring to provide the sound engineer with objective measurements that can be acted upon immediately to ensure that hazard substitution is in fact occurring. The most appropriate timeframe for measuring and monitoring sound levels is an open question. The various regulations in Table 1 stipulate timeframes ranging from 1 min to 4 h and further research is needed to better understand the most appropriate duration from an operator point of view. In any case, awareness of the sound level at any point in time (irrespective of the measurement timeframe), should help to prevent the typical increase in sound levels that occurs over the course of an evening at a rate of roughly 3 dB per h (Williams *et al.*, 2010; Gjestland and Tronstad, 2017; Welch and Fremaux, 2017b). There is speculation that temporary threshold shift (TTS) of both audience members and staff can result in impaired loudness perception resulting in an increase in sound levels (Fortin and Héту, 1994; Welch and Fremaux, 2017a), and objective monitoring would go some way towards counteracting this effect.

Some regulations require that real-time sound levels are visible to the audience and that records of measurements are retained for inspection at a later date. However, displaying levels to audience members could encourage interference with the measurement microphone (if accessible) and lead to spurious measurements. There is also a risk that the displayed sound levels will be misinterpreted by the audience—because they are unlikely to be familiar with the L_{Aeq} designation, and may mistakenly believe that 100 dB L_{Aeq} is ‘too low for a rock concert.’ Despite the additional cost and complexity associated with record retention, it has considerable appeal not only for enforcement officers and researchers, but also venue operations. Having a historical record of sound levels would enable venues to keep track of their sound levels and evaluate how best to manage them. The Dutch approach, in which data are gathered and analysed centrally, offers both venue managers and enforcement authorities access to the same data. This model would enable a framework whereby compliance is enforced through a combination

of retrospective analysis, random venue checks, and regular calibration of measurement equipment.

Engineering controls

Restriction of access to loudspeakers

Where possible, entertainment venues should prevent audience members from being in close proximity to loudspeakers, where sound levels are at their highest. Speaker placement can be optimized to achieve efficient and consistent delivery of sound to larger audiences without over-exposing audience members closest to the stage, although in smaller venues, low ceiling height and limited floor space may constrain the options with respect to loudspeaker placement. In these cases, finding sufficient space to insert a barrier between the audience and loudspeakers may be difficult.

Provision of access to quiet respite areas

Where possible, entertainment venues should provide audience members with a quiet zone or rest area where sound levels are considerably lower than in the main performance area, and ideally below 85 dB L_{Aeq} . The area should be easily accessible and indicated with clearly displayed signs. Although spending some time in a rest area where the sound level is lower will reduce overall exposure, the risk reduction effect will be minimal because high sound levels dominate the exposure calculation. For example, if a person is in a venue where the sound level is 100 dB L_{Aeq} for 2 h, their exposure will be 8 Pa² h (or 8 times the typical workplace noise exposure standard, 85 dB $L_{Aeq,8h}$ = 1 Pa² h). If they move to a rest area for 15 of the 120 min, their overall exposure drops slightly to 7.03 Pa² h. For exposure to drop below 1 Pa² h, a person would need to spend virtually all of their time in the rest area (108 of the 120 min) and only 12 min at 100 dB L_{Aeq} .

Administrative controls

Provision of warnings

Given the acknowledgment that specified sound limits cannot be regarded as ‘safe’ it is imperative that people who attend entertainment venues are informed of the potential risk to their hearing. There are several communication channels that could be used for the provision of this information to audience members, including during event promotion, at ticket purchase points, on tickets themselves, on entry to the venue and within the venue itself. Information about sound levels should be accompanied by access to advice about how to mitigate potential risks,

including the use of hearing protection, limiting exposure time and use of 'quiet spaces' where relevant.

Personal protective equipment

Provision of earplugs

Personal protective equipment is regarded as a measure of last resort in the hierarchy of risk management controls, and the same principle applies in recreational settings. Knowing that high sound levels at entertainment venues cannot be eliminated entirely and that most venue attendees will not choose to spend their entire evening in a quiet rest area, attendees will likely be subject to at least some degree of risk, and it is therefore incumbent on venues to make protective equipment, such as earplugs, available to them. Research shows that earplugs are effective in reducing symptoms of hearing damage, such as tinnitus and TTS in those attending loud music events (Opperman *et al.*, 2006; Ramakers *et al.*, 2016). Ideally, high-fidelity earplugs should be provided either at cost price or at no cost since the availability of free earplugs has been shown to encourage usage among concert attendees (Cha *et al.*, 2015) and the relatively flat frequency response of these earplugs means that they are usually more acceptable for music venue attendees (Beach *et al.*, 2010; Bockstael *et al.*, 2015). To facilitate uptake, venues should use signs and other forms of communication to ensure that audience members are aware that earplugs are available and the locations at which they can be obtained.

Discussion

Managing the risk of hearing damage for audience members attending entertainment venues is a complex issue that involves a range of stakeholders. As noted by previous authors, regulations alone are not enough to eliminate the risk to hearing health at entertainment venues and must be part of a larger solution (Rawool, 2012) but they have the potential to contribute to a significant change in this area. If music venues become more regulated, hearing-related measures, such as reduced sound levels, regular earplug use, and access to respite areas will start to become 'normalized'. Currently, there are strong cultural norms surrounding loud music (Welch and Fremaux, 2017b; Manchaiah *et al.*, 2018) and also social norms that govern the behaviour of attendees in music venues (Chung *et al.*, 2005; Goggin *et al.*, 2008). These norms mean that high-intensity sound levels are expected and accepted, and protective behaviours are frowned upon. These norms exert a powerful influence,

not only on young people who attend music venues, but also sound engineers and venue operators, making it very difficult to change attitudes and motivate behaviour change (Landälv *et al.*, 2013; Widén, 2013). However, as regulation becomes more widespread, and the number of compliant venues increases, hearing-health practices will become more common. The benefits will be observed not only in individual venues, but in the creation of new norms, in which hearing-protective behaviours become acceptable practice. In time, these new norms could become powerful motivators to encourage behavioural change and ultimately a cultural shift towards entertainment venues that value and protect the hearing of all who enter them.

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