SOUND DISTRIBUTION FOR SAFE LISTENING IN ENTERTAINMENT VENUES: A REVIEW OF EXISTING POLICIES AND REGULATIONS

IM Wiggins National Institute for Health Research Nottingham Biomedical Research Centre, UK
Hearing Sciences, Division of Clinical Neuroscience, School of Medicine, University of Nottingham, UK
KI Liston Nottingham Trent University, Confetti ICT, Nottingham, UK

1 INTRODUCTION

The purpose of this report is to review the literature on sound distribution in entertainment venues as it pertains to safe-listening practices; that is, the enjoyment of amplified sound without endangerment to hearing health. The report was put together at the request of the Ear and Hearing Care team at the World Health Organization (WHO), as part of a wider body of work to inform the development of a regulatory framework for control of sound exposure in recreational settings.

By sound distribution, we refer to the uniformity (or otherwise) of sound levels throughout a venue, as results from the interaction between the design and operation of the electroacoustic sound-reinforcement system and the acoustical characteristics of the venue. It is important to note that the risk of sound-induced hearing injury is ultimately determined by the sound pressure level (SPL) at a listener's eardrums, combined with the duration of the exposure. Sound distribution cannot affect "what is safe" in this respect. Sound distribution does, however, play a key role in determining whether safe listening conditions will be achieved for all members of an audience, or for some, but not others. Good sound distribution may also be a pre-requisite to be able to comply with safe-listening regulations in practice.

In the present report, we review the evidence-base on sound distribution in entertainment venues in the context of existing "safe-listening" policies and regulations from around the world. We critically review requirements of such policies and regulations that relate to sound distribution, drawing on peer-reviewed literature, theory and calculation to assess their expected effectiveness.

2 A REVIEW OF THE EVIDENCE-BASE ON SOUND DISTRIBUTION IN ENTERTAINMENT VENUES

Beach et al. [1] comprehensively reviewed current policies and regulations in countries across the world designed to protect the hearing of patrons and audience members within entertainment venues. Most countries do not have such regulations, but a few, most notably in Europe, have developed detailed policies and regulations to address this issue. Here, we review the evidence-base on sound distribution in entertainment venues, anchoring the discussion around relevant requirements of current "safe-listening" policies and regulations.

2.1 Control of sound levels at most-exposed vs representative audience locations

Most current policies and regulations stipulate some form of sound-level limit that should not be exceeded, for example, $L_{Aeq,4hr}$ = 100 dB. There is variation from country to country in the exact limit(s) imposed, as well as the required integration period and frequency weighting. Of direct relevance to the present report, there is also variation in where it is recommended (in some cases mandated) that the measurements should be made. For instance, Swiss regulations [2], German industry standard DIN 15905-5 [3], and guidelines from the UK Health and Safety Executive[i] state that measurements should be made in the audience area at a position where the highest sound level is expected (i.e. at the most-exposed location). Where this is not possible, the measurement can be made at an alternative location (typically the FOH mixing position), with an appropriate correction made to account for the difference in sound level between the two locations. In other cases, for example under certain Belgian regulations [4], Norwegian guidelines [5], and a Dutch covenant [6], it is required that the sound level is measured at a "representative" location (often assumed to be at FOH).
This variability in approach raises several important questions related to sound distribution: (1) How much do sound levels vary across the audience area in different sorts of venue? (2) Can sound levels measured at FOH be considered representative? (3) If a correction is to be applied to account for a sound level difference between locations, how should this be implemented to ensure its validity? These questions are addressed in turn below.

2.1.1 How much do sounds levels vary across the audience area?

Measuring sound levels at multiple locations within a venue is challenging. Ideally such measurements would be made simultaneously, to ensure that all measurements are influenced by the same acoustic events (sound levels will vary somewhat from song to song and from set to set during a concert or festival); however, this requires as many sound level meters (SLMs) as there are measurement locations, which may be prohibitively expensive. Also, when measurements are made while an event is underway, access to the desired measurement locations is not always possible, and measurements may be subject to unquantified interference from crowd noise.

One approach to dealing with the problem of access is to fit volunteer audience members with wearable noise dosimeters, allowing their personal sound exposure to be logged. Interpretation of sound levels measured in this way can be challenging, however, as there may be relatively little control over precisely when and where the volunteers do their listening. The reliability of dosimeter measurements can also be affected by differences in how the microphone is worn and the addition or removal of items of clothing [7, 8]. An alternative approach is to make measurements before an event begins, when the sound system can be excited by a reproducible test signal and controlled measurements can be made sequentially at different locations. However, it can be hard to find a suitable period during which the measurements can be made without interference from other noise-generating activities on site, especially at temporary events where setup time is usually limited [9, 10]. Also, the presence of an audience can change the acoustics of a venue, and so sound levels measured in an unoccupied venue may not be representative of those that will occur during the actual performance (when the audience is present) [11].

[i] www.hse.gov.uk/event-safety/noise.htm (accessed 6 May 2020)

Despite these challenges, there are several studies in the literature that report the distribution of sound levels throughout one or more entertainment venues. In an early example, Brawley [9] measured sound levels and spectra at ten different locations within each of three empty US sports arenas (capacity between 11,000 and 22,000) visited by a touring musical act. The same sound system was temporarily installed in each arena and excited by a pink-noise test signal. Taking the FOH mixing desk as a reference position, Brawley found that sound levels were within ±3 dBA of the reference across all tested audience locations (maximum range across audience locations within any one arena was between 2 and 6 dBA). Brawley concluded that the sound system could provide consistent coverage and SPL across the audience area in venues of varying size and capacity.

Other studies have reported a greater level of variability across the audience area at large-scale events. Mercier et al. [12] used a combination of personal dosimeters and fixed SLMs to measure sound levels throughout the audience area at the Paleo Festival in Nyon, Switzerland, during July 2001. Based on measurements made during two sets performed on the largest of the festival's four stages (capacity 25,000), Mercier et al. observed sound levels that varied by 8–12 dBA across the audience area (at distances between approximately 10 and 60 m from the stage). Interestingly, (A-weighted) sound levels were not always maximal for audience members standing closest to the stage, likely due to the use of flown loudspeaker arrays at either side of the stage that would have projected their maximum output towards a region further back into the audience area.

While flying the main loudspeakers above ground level is common practice at larger events, the subwoofers are still routinely placed at ground level in front of, on, or underneath the stage. This can result in pronounced front-to-back level differences across the audience area in the low-frequency range (30–100 Hz). For example, in a case study before the Pitchfork music festival in Chicago in July 2019, Hill et al. [10] measured a low-frequency level difference of 17 dB over distances of around 2.5 to 30 m from the front of the stage (with audience absent). There is some evidence to suggest that, due to interference effects, the effective decay of the low-frequency sound pressure level with distance can actually be lessened when an audience is introduced [13]. However, this is a complex effect, dependent on frequency, audience density, and precise measurement position, and substantial front-to-back low-frequency level differences are still to be expected when ground-stacked subwoofer arrays are used.

Dramatic variability across the audience area in the low-frequency range (30–100 Hz) will have negligible effect on A-weighted sound levels, since A-weighted measurements are minimally sensitive to these low frequencies. Use of the C-weighting curve, instead of or in addition to A-weighting, would in principle capture this variation in the low-frequency range. While the risk of hearing injury associated with intense low-frequency exposure remains uncertain, it is noteworthy that individuals standing in the front row of the audience (as well as security and event personnel) at large-scale events may be consistently exposed to low-frequency levels in the range 120–130 dBC peak [10].

Turning from festival stages to smaller-scale, indoor venues, McGinnity et al. [14] measured sound levels throughout six small- to medium-sized live music venues in Melbourne, Australia. As part of a longer-term study into the impact of a software-based sound-management system, McGinnity et al. used dosimeters mounted in fixed locations (in line with the main sound source on stage, at FOH, in the middle of the dance floor, at the bar, and at the ticket desk) to log sound levels during live performances. On average across venues, the stage was the loudest area, followed by the dance floor, FOH, and then the bar. If we assume that audience members standing directly in front of the stage would have been exposed to levels similar to those measured on stage, and that levels measured at FOH were representative of the rear of the audience area, then "Stage - FOH" should give a reasonable estimate of sound-level variability across the audience area. A secondary analysis of McGinnity et al.'s data reveals that levels on stage were on average 4.1 dBA higher than at FOH, although the range across venues was large (-2.9 to 8.7 dBA). The substantial variability across venues reflects the fact that the venues studied were highly heterogeneous in terms of size and layout, including in distance from stage to FOH.

A study by Griffiths [15] is informative because identical methods were used in both indoor and outdoor venues of varying size. This study was commissioned by the UK Health and Safety Executive and aimed to quantify the difference in sound level between FOH and the "barrier location" (the nearest position to an operational loudspeaker that the audience were allowed to approach). As expected, sound levels at the barrier location were higher than levels observed anywhere else within the audience area in all but one venue (where the level at the barrier location was within 1 dBA of the maximum level). For outdoor concerts, the sound level at the barrier location was on average 8.1 dBA higher than at FOH (range 3.1 to 14.9 dBA). In indoor venues, the average difference was slightly smaller at 5.4 dBA (range -1 to 12 dBA). A smaller average level difference between FOH and the barrier location in indoor compared with outdoor venues is consistent with a typically smaller physical distance from front to back of the audience area combined with the partially "equalizing" effect of room reverberation. However, given the relatively small number of venues studied (four outdoor and seven indoor) and the wide variability even between venues of the same type, it is difficult to draw firm conclusions regarding any overall difference between indoor and outdoor venues.

A study conducted for the Danish Sound Technology Network [16] also measured sound levels across at least nine locations throughout the audience area at a range of venues (one large outdoor festival stage, two tented venues, and five indoor venues). The report states that sound levels at the individual measurement locations typically varied from the mean response by ±5 dB, although numerical data were not reported, preventing a detailed analysis.

Other studies have used personal dosimeters to log the sound exposure of workers performing different roles within venues, e.g. musician, sound engineer, bar staff, etc. [7, 17]. The results of these studies suggest that workers in different roles can have very different sound exposures, though this is strongly influenced by differences in working patterns between roles, and few workers spend much of their time directly in the audience area. It is therefore not straightforward to interpret the results of these studies in terms of sound-level variability across the audience area.

To summarise, the extent to which sound levels vary across the audience area can be very different from one venue to another. Average values appear to be roughly 5 dBA for indoor venues and 8 dBA for outdoor venues. However, the range of variation even amongst venues of the same type is approximately 12 dBA, suggesting that such generalisations may not be particularly helpful. Even larger front-to-back level differences (up to 17 dB and beyond) have been measured or predicted in the low-frequency range (30–100 Hz) in the case that ground-based subwoofers are used.

2.1.2 Can sound levels measured at FOH be considered representative?

In the face of such variability in sound levels throughout individual venues, it seems clear that sound levels measured at any one location are unlikely to be representative of the entire audience area. Typically, the FOH mixing position is located quite far back from the stage, and so levels measured at FOH will, in general, approximate levels experienced in the rear half of the audience area.

A study by Tronstad and Gelderblom [8] aimed to assess empirically whether levels measured at FOH are representative of those experienced by audience members. FOH measurements were compared with personal dosimeter measurements taken during outdoor concerts at the 2014 Øya festival in Norway. The dosimeters were worn by four student volunteers who were instructed to act as normal festival participants, moving around the site freely. The distributions of levels measured at FOH and by the personal dosimeters had similar central values. This suggests that levels measured at FOH can be used to assess audience exposure, however, some qualifying comments are in order. Firstly, the number of volunteers used in this study was small. Secondly, Tronstad and Gelderblom noted that the distribution of sound levels measured with the dosimeters was broader than at FOH, suggesting that some participants will have experienced exposures lower than those at FOH, but others higher. Finally, participants in the study were forewarned about the risks of loud sound exposure at concerts, which may have influenced their behaviour (for example, by leading them to favour listening positions further away from the loudspeakers).

In indoor venues, room reverberation will generally act to make sound levels more uniform throughout the audience area. In their study of long-term trends in sound levels at the UKA festival in Norway, Gjestland and Tronstad [18] did not measure levels within the audience area (only at FOH), but they did comment on the effect of reverberation on level variability. The UKA festival concerts were held in a large circus tent accommodating 4,000 people. This venue had significantly longer RT at high frequencies (where the tent fabric was reflective) than at low frequencies (which "leaked" through the tent fabric to a greater degree). Gjestland and Tronstad stated that attendees were located outside the critical distance from most of the loudspeakers in a more or less diffuse sound field; on this basis they assumed that A-weighted levels (more affected by mid-to-high frequencies) would be relatively stable across the audience area and that FOH levels could be considered representative for a major part of the audience. They noted, however, that attendees standing close to the subwoofers positioned at ground level along the front of the stage would have been exposed to higher levels of low-frequency sound. This raises an important point: it is possible for FOH sound levels to be representative of audience exposure at some frequencies, but not others. This will depend heavily on the acoustics and sound-system design of each individual venue.
The data from McGinnity et al. [14] study of six small- to medium-sized live-music venues are also informative here. Sound levels measured in the "middle of the dance floor" [ii] during performances were on average 2.0 dBA higher than at FOH (range -2.2 to +4.4 dBA). This suggests that FOH measurements slightly underestimate levels in the middle of the audience area on average. However, the difference between FOH and the central audience area varies by more than 6 dBA across venues, suggesting that caution is required in assuming that a similar relationship holds for all venues.

To summarise, how representative FOH measurements are of audience exposure will vary substantially from one venue to another. On average, FOH measurements are likely to systematically underestimate audience exposure, especially compared to the most-exposed locations.

2.1.3 How should corrections for sound level differences between locations be implemented?

If it is desired to ensure "safe-listening" conditions for all members of an audience, it will be necessary to apply a correction to FOH measurements to estimate exposure at the most-exposed audience

[ii] Note that the precise measurement position varied from venue to venue according to practical considerations, e.g. mounted to a pillar, suspended above the audience, etc. This is a source of between-venue variability in the measurements.

location (FOH will often be the most practical location to measure sound levels during a live event, given typical access and security considerations). For such corrections to be valid, it is critical to take issues of sound distribution into account.
In their study of sound exposure at the Paleo festival in Nyon, Switzerland, Mercier et al. [12] explicitly set out to establish whether it is possible to develop a general correction factor between the locations where the public is most heavily exposed and the FOH mixing desk. They found that the required correction factor depended on multiple factors, including meteorological conditions, local topography, audience density, and, especially, the spectral balance between low and high frequencies, which varies from one musical set to another. Across nine different concerts taking place on the same stage, the required correction factor varied across an 8-dBA range, from 5.3 to 13.3 dBA.

An effective way to account for the variation in spectral balance between sets could be to implement the correction on a frequency-dependent basis. In this approach, the level difference between FOH and the most-exposed location would be pre-measured on, say, a one-third-octave-band basis. Spectral levels measured at FOH during a performance would then be adjusted on a frequency-specific basis to estimate the spectrum at the most-exposed location. At this point, an appropriate frequency weighting can be applied (e.g. A-weighting), and an overall weighted level calculated for the most-exposed location. Such frequency-dependent correction is included as an option in some existing sound-management systems, for example, the system deployed across Norway under the Musikkutstyrsordningen scheme [19]. Despite this technological advancement, Støfringsdal notes that it is not trivial to obtain a robust measure of overall level differences between FOH and audience areas close to the stage. This is because audience members in these areas are exposed not just to sound from the main PA system, but also to sound coming directly from the stage, which is variable in nature and more difficult to quantify.

A further potential complication arises from the use of correction factors measured in *unoccupied* venues to predict worst-case exposures in *occupied* venues. If the introduction of an audience changes the way in which sound propagates throughout the venue, the correction may no longer be valid. As noted previously, the introduction of an audience can have a complex effect on low-frequency sound propagation from ground-based subwoofers due to interference effects [13]. Propagation of mid-to-high-frequency sound can also be affected by the introduction of an audience, since an audience forms an effective absorber of sound at these frequencies [11]. If line-of-sight between a loudspeaker and a listening/measurement position is blocked by the audience, the level of high-frequency sound reaching that position is likely to be heavily attenuated. Through providing additional sound absorption, the introduction of an audience can also significantly reduce the RT of indoor venues in the mid-to-high-frequency range. The effect on RT is most pronounced in venues that have a large audience area relative to their overall size. To the best of the authors' knowledge, the impact of these factors on the validity of correction factors between FOH and the most-exposed audience location has not been empirically assessed to date.

2.2 Requirements for an exclusion zone around loudspeakers

Some current policies and regulations include requirements restricting audience access to the area around loudspeakers, where sound levels are generally at their highest. For instance, guidelines from the UK Health and Safety Executive[iii] state that, wherever possible, patrons should not be allowed within three metres of any loudspeaker, and that under no circumstances should the separation be

[iii] www.hse.gov.uk/event-safety/noise.htm (accessed 6 May 2020)

less than one metre. Similarly, a local restriction imposed by the City of Ghent in the Flanders region of Belgium requires that audience members should be kept at least one metre away from any loudspeaker [1]. Austrian regulations [20] require patron access to the area around loudspeakers to be restricted if the sound level exceeds 100 dB L_{Aeq} in that area.

2.2.1 How much do sound levels increase close to loudspeakers?

Sound levels can be expected to rise rapidly as one approaches a loudspeaker. Insight into the magnitude of this increase can be obtained by considering the hypothetical case of a point source in the free field; that is, an infinitely small sound source located well away from any boundaries or surfaces (Figure 4). In this scenario, moving from 3 m away from the source to 1 m away would see an increase in sound level of 9.5 dB. Continuing to approach to within 30 cm of the source would see a further increase in level of 10.5 dB. In combination, the level 30 cm from the source would be 20 dB higher than the level at 3 m.

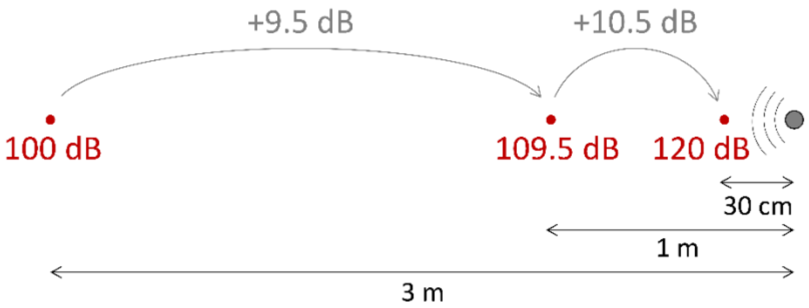

Figure 1 Illustration of rapidly increasing sound level as one approaches a sound source. These values are for the hypothetical case of a point source in the free field; the change in sound level as one approaches a real loudspeaker in a given environment may differ from the values shown here.

Put another way, if the maximum period for which it was considered safe to listen to this sound source from a distance of 3 m away was 4 hours, then at a distance of 30 cm it would be safe to listen for only 2 minutes. In reality, loudspeakers in entertainment venues are not point sources in a free field: they are physically large, contain multiple interacting drivers, and radiate into a complex acoustic environment. This means that the change in sound levels as one approaches a real loudspeaker may differ from the hypothetical case reported above. Nonetheless, this analysis makes clear that the increase in sound levels close to a loudspeaker could be very substantial indeed. Restricting access to the area immediately surrounding loudspeakers is therefore a sensible precaution, where this is practicable.

2.2.2 Should all loudspeakers be considered equal?

McCarthy [21] details four different classes of loudspeaker as a guide to specifying the different components of a sound-reinforcement system. The maximum output capability, in terms of the peak SPL that these speakers can produce at a distance of 1 m, varies dramatically across the four classes. Specifically, McCarthy describes “Class 1” speakers as having a maximum output capability in the 110-119 dB range, while “Class 4” speakers, the most powerful models, have a maximum output capability of 140 dB and above. In light of this 30+ dB range, it clearly is inappropriate to consider all loudspeakers as being equal. Thus, while restricting access to the area around loudspeakers based purely on a distance criterion (e.g. no access within one metre) may be a sensible precaution, it is important to keep in mind that this does not account for differences in output capability between loudspeakers.

It should be noted that the maximum output levels stated above are peak values, and long-term average sound levels from each class of loudspeaker can be expected to be significantly lower. Nonetheless, based on a 30 dB difference in relative output between a “Class 1” and a “Class 4” loudspeaker, if it was considered safe to listen to the Class 1 loudspeaker at a certain distance for 4 hours, it may be safe to listen to the Class 4 loudspeaker at the same distance for only 14 seconds.

2.3 Requirements for a respite zone

Current regulations in some countries, for example Switzerland [2], France [22], and Belgium [4], require venues to provide a quiet respite zone under certain conditions. This is to give patrons somewhere to go to rest their ears, away from high sound levels encountered elsewhere in the venue. Typically, the hourly sound level in the respite zone must be below a limit of around 80–85 dB L_{Aeq}.

There may exist cases where a venue wishes to provide a respite zone that is acoustically coupled to the main listening space, i.e. where airborne sound transmission is possible between the main listening space and the respite zone. Careful acoustic design would be essential in such cases, to achieve sufficient attenuation of sound from the main listening space. This would likely require a combination of extensive acoustic screening (i.e. acoustic barriers) and sound absorption to attenuate direct and reflected sound, respectively. Even with extensive treatment, such a solution is unlikely to be feasible in the majority of cases.

More commonly, venues will provide a respite zone in a different room from the main listening space. Adequate control of the sound level within the respite zone should in most such cases be achievable through standard architectural acoustic practices (e.g. specification of suitable wall and floor constructions capable of providing adequate sound insulation; provision of sound absorbing room-acoustic treatment within the respite room). If sound spillage from the main listening space into the respite zone through interconnecting doors is an issue, this may be solved by introducing a double-door arrangement, with the lobby area in between the two door sets treated with sound-absorbing materials.

2.4 Requirements for optimized sound-system design

Every venue and event is different, and the optimum means of delivering high-quality yet “safe” sound to the audience may differ accordingly. In some jurisdictions, this complexity is reflected in the regulations that have been introduced to protect patrons’ hearing. For instance, in the Flanders region of Belgium, event organizers are required to prepare a “noise plan” in the case of permanent sound installations that belong to the establishment [23]. The noise plan is to be prepared by a suitably qualified expert and must contain, amongst other information, evidence that the choice and arrangement of loudspeakers has been optimized to achieve the most efficient possible distribution of sound, as well as measurements of the sound level at a minimum of five locations throughout the venue (one of which is the main measurement location where sound levels are to be regulated). In the Brussels region, venues in which the highest sound levels are expected must appoint a reference person who is responsible for ensuring not only the “best possible configuration” of the sound system, but also its appropriate operation so as to comply with the imposed sound-level limits [4].

Requirements such as these, which necessitate professional input, will impose an additional financial burden on venue owners and event organizers, and may not be appropriate for all countries and contexts. Nevertheless, they highlight that successful compliance with recommended limits for sound exposure depends on appropriate sound-system (and acoustical) design, as well as competent operation of the system during ongoing use.

3 CONCLUSIONS

3.1 Spatial variability in sound levels throughout existing venues

The primary requirement of most existing policies and regulations designed to protect the hearing of patrons in entertainment venues is some form of sound level limit(s) that should not be exceeded. There is variability in where it is required that measurements should be made. Due to typical access restrictions and security considerations, it is common practice to make these measurements at the FOH mixing desk. Prior studies suggest that sound levels measured at FOH are likely to underestimate exposure across much of the audience area, significantly so for the most-exposed locations. The difference in sound level between FOH and the most-exposed audience location is, on average, around 5 dBA in indoor venues and around 8 dBA at outdoor events. However, this varies significantly between venues, even amongst those of the same type, and level differences in excess of 12 dBA have been observed. Even larger front-to-back level differences may occur in the low-frequency range (30–100 Hz) at large-scale events employing ground-based subwoofers. Further research is needed to understand the extent to which exposure to intense low-frequency sound exacerbates the risk of sound-induced hearing injury.

3.2 Implications for sound-level monitoring

Where regulations require sound levels to be controlled at the most-exposed audience location, a practical solution may be to measure levels at FOH, but to make an appropriate correction to account for the difference in level between FOH and the most-exposed location. The required correction would typically be pre-determined based on measurements made when the venue is unoccupied. Several factors may impact on the validity of this approach: 1) the overall (e.g. A-weighted) level difference between FOH and the most-exposed audience location will vary with the spectral balance of the music; 2) the presence of an audience can alter both direct-sound propagation and room reverberation, meaning that measurements made in an unoccupied venue may not be representative of those that will occur during an actual event; and 3) the estimated level at the most-exposed location will account primarily for sound coming from the PA system, and not for a highly variable and potentially significant contribution due to sound spillage from the stage and/or audience noise. The first point can in principle be circumvented by implementing the correction on a frequency-specific basis. The impact of points 2 and 3 is harder to quantify and, to the best of the authors' knowledge, has not been studied empirically to date. These complications notwithstanding, there may be merit in measuring and controlling sound levels at FOH, in so far as this will draw the attention of sound engineers (and other stakeholders) towards the risk of excessive sound levels and, hopefully, reduce the occurrence of extreme excursions beyond recommended levels.

3.3 Supplementary requirements

Some current policies and regulations also specify an exclusion zone around loudspeakers. Such restrictions are well motivated: sound levels rise rapidly as one approaches a loudspeaker, and there are few, if any, circumstances where it would be appropriate for audience members to sit or stand immediately next to a sound-reinforcement loudspeaker. However, taken in isolation, distance-based restrictions are somewhat arbitrary: the peak output capability of different types of loudspeaker used in sound-reinforcement applications can vary by upwards of 30 dB, meaning that it may be safe to stand one metre away from a particular make and model of loudspeaker, but extremely hazardous to stand at the same distance from another. Restricting access to the area around loudspeakers is therefore perhaps best considered as a supplementary requirement designed to move the “most-exposed” audience location further away from the loudspeakers (and therefore buy headroom to increase the sound level without causing dangerous conditions at the most-exposed location). On a practical note, it is also worth considering the factors that might drive patrons to occupy high-risk locations (e.g. over-crowding, poor sight lines to the stage) and assess what might be done to mitigate these, since patrons may not be occupying these locations out of free choice.

Some current policies and regulations stipulate that a respite zone must be provided with quieter average sound levels. Sound distribution, in terms of both the sound-system design and the venue acoustics, must be conducive to achieving the required level of sound attenuation between the main listening space(s) and the respite zone.

Ultimately, all venues and sound systems are different, and even a well-designed sound system in a venue with favourable acoustics will only meet safe-listening requirements if maintained and operated appropriately. Accordingly, in at least one European country, current regulations require venues to engage a suitably qualified professional to advise on an optimal sound-system design and for there to be a nominated person who is responsible for the upkeep and safe operation of the sound system. It must be noted, though, that imposing these as formal requirements places a considerable burden on venues and event promoters. An alternative approach would be to disseminate guidance and education around these topics, to help empower venue owners, event promoters and sound engineers to achieve high-quality sound without undue risk to hearing.

4 REFERENCES

1. Beach EF, Mulder J, O'Brien I, Cowan R. Background paper prepared for the World Health Organization World Report on Hearing (Current status of policies and regulations in countries across the world to protect the hearing of patrons and audience members within entertainment venues). 2019.
2. Ordinance on the Protection of Audiences from Exposure to Hazardous Sound Levels and Laser Beams (Sound Levels and Laser Ordinance, SLO), (2012).
3. Deutsches Institut für Normung. DIN 15905-5: Event Technology - Sound Engineering - Part 5: Measures to prevent the high-frequency exposure of electroacoustic sound systems. 2007.
4. Besluit van de Brusselse Hoofdstedelijke Regering tot vaststelling van de voorwaarden voor het verspreiden van versterkt geluid in voor publiek toegankelijke inrichtingen (Decree of the Government of the Brussels-Capital Region laying down the conditions for the distribution of amplified noise in establishments that are open to the public), (2017).
5. Norwegian Directorate of Health. IS-0327 Musikkanlegg og helse Veileder til arrangører og kommuner (Music and health: Guide to organizers and municipalities). 2011.
6. The Netherlands Ministry for Health Welfare and Sport. Derde convenant preventie gehoorschade versterkte muziek (Third covenant for the prevention of hearing damage in amplified music). 2018.
7. Butterfield D. Measurement of noise levels that staff are exposed to at live music events. 2006. Report No.: RR517.
8. Tronstad TV, Gelderblom FB. Sound exposure during outdoor music festivals. Noise & health. 2016;18(83):220-8.
9. Brawley JS. Sound-Level Distribution of Rock Concert Sound Systems. 91st Convention of the Audio Engineering Society; October 1, 1991; New York, USA1991.
10. Hill AJ, Kok M, Mulder J, Burton J, Kociper A, Berrios A, editors. A case study on sound level monitoring and management at large-scale music festivals. Institute of Acoustics – Conference on Reproduced Sound; 2019 2019-11; Bristol, UK.
11. Adelman-Larsen NW, Thompson ER, Gade AC. Suitable reverberation times for halls for rock and pop music. The Journal of the Acoustical Society of America. 2010;127(1):247-55.
12. Mercier V, Luy D, Hohmann BW. The sound exposure of the audience at a music festival. Noise & health. 2003;5(19):51-8.
13. Shabalina E, Vorländer M, editors. Influence of audience on propagation of sound at low frequencies. Acoustics 2012; 2012 2012-04-23; Nantes, Francehttps://hal.archives-ouvertes.fr/hal-00811159/document

https://hal.archives-ouvertes.fr/hal-00811159/file/hal-00811159.pdf.
14. McGinnity S, Mulder J, Beach EF, Cowan R. Management of Sound Levels in Live Music Venues. Journal of the Audio Engineering Society. 2019;67(12):972-85.
15. Griffiths JET. A survey of sound levels at pop concerts. 1991. Report No.: 35/1991.
16. DELTA SenseLab. Report No. 010-2013: Live concert sound quality - Measurements and assessments of eight concert venues. 2013 30 August 2013. Report No.: SenseLab 010-2013.

17. Gunderson E, Moline J, Catalano P. Risks of developing noise-induced hearing loss in employees of urban music clubs. American journal of industrial medicine. 1997;31(1):75-9.
18. Gjestland T, Tronstad TV. The efficacy of sound regulations on the listening levels of pop concerts. Journal of Occupational and Environmental Hygiene. 2017;14(1):17-22.
19. Støfringsdal B, editor Expected Sound Levels at Concert Venues for Amplified Music. Auditorium Acoustics 2018; 2018; Hamburg, Germany.
20. Lärmschutzrichtlinie für Veranstaltungen (Noise protection directive for events), (2011).
21. McCarthy B. Sound Systems: Design and Optimization. Oxford, UK: Taylor & Francis Group; 2016.
22. Décret no. 2017-1244 du 7 août 2017 relatif à la prévention des risques liés aux bruits et aux sons amplifiés (Decree no. 2017-1244 of 7 August 2017 relating to the prevention of risks linked to amplified noise and sound), (2017).
23. Departement Leefmilieu Natuur en Energie. Technische handleiding geluidsnormen voor muziekactiviteiten (Technical manual: Sound standards for music activities). Flemish Environment Administration; 2016.