Sound level measurement, monitoring, management, and documentation in music venues

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This document contains review of evidence on sound level measurement, management and documentation in music venues. The document was prepared by Dr Johannes Mulder from the Australian National University in Canberra, Australia, and Dr Siobhan McGinnity from The University of Melbourne, Australia for the WHO Make Listening Safe initiative.

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SOUND LEVEL MEASUREMENT, MONITORING, MANAGEMENT, and DOCUMENTATION in MUSIC VENUES

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Acknowledgment

The authors have both published a number of studies in this field. On the one hand this introduces a certain bias, on the other, this provides familiarity with the relevant literature as a point of departure. Two recent publications, which JM contributed to, contain overlap with this report, (1) and (2) and they are strongly recommended as background literature to this document. SM performed the systematic literature search, JM prepared this report. We would like to thank Elizabeth Beach and Ian Wiggins for their support in preparing this.

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1 Introduction

Audiences in (amplified) music venues are regularly exposed to high sound pressure levels (SPL). For many individuals this can contribute to permanent hearing damage from entertainment noise. In order to make listening less risky (if still not safe) these high SPLs need to be monitored and, where feasible, brought down. SLMMM for Sound (pressure) Level Measurement, Monitoring, and Management describes the tools, procedures and heuristics that are in use around entertainment events, whether considering hearing damage, occupational health and safety or environmental noise. Ideally that abbreviation would read SLMMMD, with a D for documentation, since creating durable records of sound exposure for individual events is increasingly required.

In order to develop effective, evidence-based tools and strategies for SLMMM, research is needed to: understand what is occurring in venues, what can be done to reduce sound exposure, and finally, assess whether what interventions are effective. Data collection projects in the real-world face methodological challenges that arise when measurements are taken in complex uncontrolled environments. In the ecology of a music venue few parameters can be fixed in order to design studies that irrefutably answer questions, let alone test hypotheses. To illustrate this ecological intricacy, two contextual sections precede a third section that reviews a number of case studies.

The first section discusses recent scholarship into the history of loud pop and rock music amplification, followed by a typology of music venues. The second section segues into a discussion of monitoring and on-stage sound as well as a discussion on the problems of enforcing environmental noise regulations in an urban environment. The third section reviews current SLMMM research and the fourth section provides a discussion of a number of questions that form the point of departure for this report. Those initial questions are:

1. *What is the evidence on the use and implementation of sound limits in entertainment venues?*
2. *What are the commonly implemented sound limits?*
3. *Is there information on A- and C-weighted limits?*
4. *Should average, maximum or both limits be applied?*
5. *What is the current evidence on sound measurement in venues?*
6. *What class of device is normally used for measurement?*
7. *Where does the measurement take place?*
8. *How long should the measurement be?*
9. *How often should the measurement be done?*
10. *Who is normally doing the sound measurement?*
11. *How are sound limits enforced by government authorities?*

2 Literature review

This report is in part informed by a systematic literature review into the topic of SLMMM in entertainment, specifically venues that present electronically amplified live music in the period 2016-2019. The aim of the review was to ascertain that all studies related to the topic are covered. Keyword combinations in English (e.g. ‘sound level management’ and ‘music’) were used to explore the databases of Pubmed, The Audio Engineering Society, IEEE Xplore, Inter-Noise conference proceedings. Relevant studies already known to the authors were incorporated, including two resources in French and German (3, 4). The search data is provided in appendix B.

3 Contextual background

3.1 A brief history of loud amplified music.

> What is clear is that if "loudness" is a relevant concept to understand rock music in the late 1960s, live sound technology needs to be acknowledged in the first place. How and if this equipment was heading towards louder sounds is something that cannot be concluded from quantifiable data alone. Cultural explanations should be included and historical elucidations should guide and warn us against technological determinism.
>
> *Sergio Pisfil (5)*

The origin of loudly amplified live rock and pop music is best documented in the UK and the US, roughly pinpointed in the mid-to-late 1960s. Two different broad trajectories stand out. Firstly, after a series of inaudible concerts by The Beatles in North American sports stadiums, there was a need to address very large, loud, audiences in unfavorable acoustic conditions. Secondly, at the same time, well documented in the case of English rock band The Who, powerful guitar amplifiers appeared on the stages of London's small urban venues. Increasing power of guitar amps triggered an on-stage loudness race, with increasing levels of vocal reinforcement and ultimately the amplification of other instruments such as drum kits to compete with the guitars and vocals.[1] This became a new practice of 'full amplification', which emerged in parallel to the existing practices of 'sound reinforcement'. Where the latter, going back to the 1930s, was aimed at adjusting acoustical imbalances (e.g. amplifying a vocalist or quiet instrument in order to be heard in balance with a larger ensemble), the former became an aesthetic outcome in itself.

Two outdoor festivals in 1967, one in the US (Monterey International Pop Festival in July), one in the UK (7th National Jazz and Blues Festival, Windsor in August) are considered milestones in the emerging amplification practice (5, 6). A number of new technological developments were observed here: transistor amplifiers driving efficient column loudspeakers in the UK; and in the US, the 'Voice of the Theatre' horn-loaded loudspeaker (that had been in use in cinemas since the 1940s), driven by up to 1,000 Watts of vacuum tube amplifiers (not a lot in today's terms). Furthermore, in both cases there was a basic form of artist-foldback (or monitoring) from loudspeakers on the side of the stage, so-called 'side-fills'. Newly developed sound mixing desks were used to blend the signals from different microphones. In 1967 these were positioned on the side of the stage, and the operator was unable to experience what the audience could or could not hear. The Woodstock festival, two years later, in 1969, is generally considered another early occurrence of the modern sound amplification system (7, 8). Even though the problem of how best to manage on-stage monitoring was not solved, the mixing desk was now positioned amongst the audience (i.e. at front of house (FOH)).

Another novelty that emerged at this time was the problem of environmental noise and nuisance to neighbors from amplified music. At the 1967 Windsor Jazz and Blues festival, inventor, entrepreneur and operator Charlie Watkins was arrested and brought before a

[1] http://www.thewho.net/whotabs/gear/pa/pa6366.html [accessed January 2020]

judge for breaking the peace.[2] Hearing health risks were also identified and researched from much the same period (see table 1).

Figure 12. Radiology of articles concerning the auditory effects of rock music

YEAR	TITLE OF PUBLICATION	AUTHORS' ACADEMIC DISCIPLINES	JOURNAL
1967	Acoustic Trauma from Rock-and-Roll Music	Institute of Medical Sciences, Pacific Medical Center, San Francisco. Department of Otolaryngology, Department of Surgery, Univ. of California School of Medicine	California Medicine
1968	Noise-Induced Hearing Loss and Rock and Roll	Department of Audiology and Speech Sciences, Michigan State University	Arch Otolaryngol
1969	Effect of Too-loud Music on Human Ears But, Mother, Rock'n Roll HAS to be loud!	Audiology Division of the Speech Clinic, Institute for Human Adjustment, The University of Michigan	Clinical Pediatrics
1969	Ear Damage From Exposure to Rock and Roll Music	Department of Audiology and Speech Pathology, University of Tennessee	Arch Otolaryngol
1969	Modern-Day Rock-and-Roll Music and Damage-Risk Criteria	Speech and Hearing Center, Memphis State University	Acoustical Society of America
1970	Temporary Threshold Shift in Rock-and-Roll Musicians	Baylor College of Medicine, Houston, Texas.	J. of Speech and Hearing Research
1970	Auditory Fatigue and Predicted Permanent Hearing Defect from Rock-and-Roll Music	N/A	The New England J. of Medicine
1970	Hearing Loss in Rock-and-Roll Musicians	Department of Speech Science, Pathology and Audiology, University of Minnesota. Department of Otolaryngology, University of Minnesota	J. of Occupational Medicine
1972	Temporary Threshold Shift and Recovery Patterns from Two types of Rock and Roll Music Presentation	Department of Audiology and Speech Sciences, Audiology Research Laboratory, Michigan State University	Acoustical Society of America
1972	Clinical Study to Evaluate Rock Music, Symphonic Music, and Noise as Sources of Acoustic Trauma	Electrical Engineering Department, Massachusetts	Acoustical Society of America
1972	Ototraumatic Effects of Hard Rock Music	San Francisco Hearing and Speech Center. Department of Otolaryngology. Institute of Medical sciences, Pacific Medical Center, San Francisco	California Medicine

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Table 1 Early research outputs covering rock music and hearing health. Reproduced with permission from the author. (6)

3.2 A culture of loud sound

With the ability, in the early 1970s, to drive on-stage floor monitors at high SPL, the norm for amplification systems became dualistic: separate systems addressing audiences (PA) and the performers (monitors). At the same time, the Grateful Dead tried to realize high quality undistorted sound for large audiences (9). With their famous 'Wall of Sound' the aim was to combine the monitoring and PA system in one giant loudspeaker installation positioned behind the band, thus avoiding the duality of two sound systems and letting the audience experience the same sound that the band experienced.[3]

> The music that was constructed not only by musicians, but also by the audience, created a new posture of enjoying music which is similar to the excitement in sports with active physical activities of participants. This differed radically from the old fashion of passive audiences listening to music in public halls.

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[2] http://www.wemwatkins.co.uk/history.htm [accessed January 2020]
http://www.ukrockfestivals.com/nat-jazz-67-pa.html [accessed January 2020]]

[3] Feedback was cancelled out by summing two microphones with opposing polarity, one microphone picks up the intended source resulting in a different signal to the other microphone of the pair. Nick Reeder's PhD [9] considers how amplification affords participation at concerts by The Grateful Dead.

Yahata & Suzuki (10)

Several recent studies have explored the reasons why people are attracted to, and willingly expose themselves to loudly amplified music. (11-13) One (12) study sums up a number of concepts that relate to why loud music appeals:

- Physiologically: loud music arouses and excites.
- Socially: loud music can draw people together in a group, but also isolate people intimately in crowded environments.
- Psychologically, loud music can shield a person from their own unwelcome thoughts, as well as from any unwelcome intrusion by outside noise.
- Finally, loud sounds can temporarily suggest a stronger identity, particularly of power and toughness.

A second study by these authors (11) explores elements of a ‘culture of loudness’ by proposing a Conditioning, Adaptation, and Acculturation to Loud Music Model (CAALM). The model sets out how our hearing can adapt to loud sound, considering:

- the perceived benefits (i.e. the ones listed above)
- the conditioning of experiencing loud sound
- and the acculturation of an expectation of loud music.

3.3 Venue Typology

“All performances take place somewhere, inside or outside, in spaces designed for other uses or increasingly, in places specifically designed for popular music”, writes Robert Kronenburg in *Live Architecture* and: “music venues can be adopted spaces, adapted spaces, dedicated spaces or even mobile spaces”. (14) Acoustically, all venues fall between two extremes: those with the acoustics of the cave and those with the acoustics of the open air. (15, 16) In the latter, sound waves travel away from a source generally unimpeded, in the former, an enclosed space, sound waves rely on the absorptive and reflective characteristics of wall and ceiling boundaries for their itinerary. In other words, an electronically amplified performance of a band in an indoor venue will, all else the same, result in exposure to a greater sound level when compared to the same performance held in an outdoor venue. From a perspective of SLMMM the type of venue is an important parameter and generalisations with regard to sound levels must be made with utmost care.

A venue typology can be considered when using the outdoor/indoor parameter as a point of departure.[4] A further disambiguation can be made between venues where music presentation is a primary function, or one of multiple purposes.

[4] A number of different typologies of venues has been discussed by the Live Music Exchange research project. 17. Webster E. Live Music Exchange Blog [Internet]. UK2012. [cited 2020]. Available from: https://livemusicexchange.org/blog/live-music-101-4-venue-typologies-an-overview-emma-webster/.

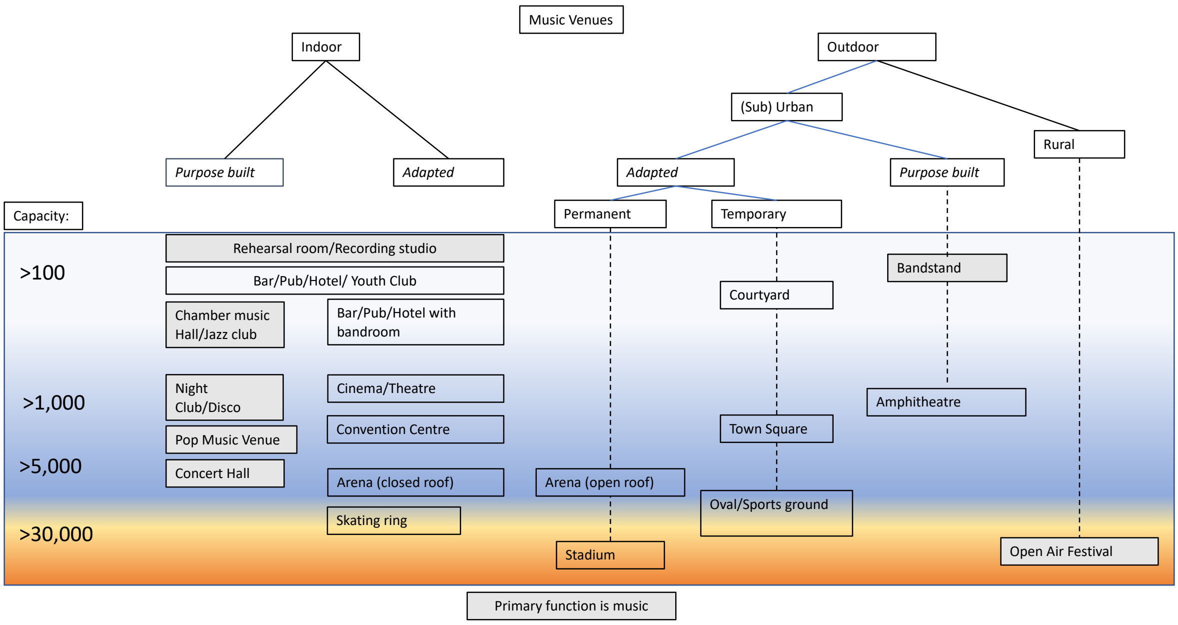

Figure 1 Venue typology based on indoor/outdoor, purpose and indication (colors) of capacity.

A recent study of the acoustic properties of twenty popular indoor pop and rock venues in Denmark (18) provides an insightful sample of the range of sizes and acoustics to illustrate that each of these venues provides a unique acoustic response to amplified music performed on stage (table 2). When considering entertainment noise and sound levels, another relevant approach to venue typology is whether there is a stage and, if so, how much sound is produced on stage. For instance, bars, nightclubs and discotheques don't always have a stage, or even a DJ booth. The source of music played through the PA can come from, for example, an automated playlist on a computer. This means that the SPL that an audience is exposed to can be controlled anywhere in the signal path from the sound-source onwards (mixer, power amplifier, loudspeakers). In other words, venue staff can turn the volume down or up with relative ease. In venues where bands play on a stage, control over the SPL an audience is exposed to is less straightforward. Operators at the FOH sound mixing desk can control the level of the system PA, but not the level of individual musical instruments (e.g. drumkits) or guitar amplifiers on stage. Reducing on-stage sound pressure levels therefore always requires a dialogue with the instrumentalists.

> Not unproblematic is the sound level produced on-stage, emitted by monitors, side-fills or instrument amplifiers. By negotiating with performers, the situation can often be improved by aiming guitar amplifiers differently (e.g. away from the audience, shooting across the stage) or the use of in-ear monitoring.[5] *Werner Grabinger (4)*

[5] Translated from German: Nicht unkritisch ist bei manchen Konzerten der von der Bühne kommende Schallpegel, verursacht durch Monitoring, Sidefills oder Instrumentenverstärker. Durch Verhandlungen mit den Musikern lässt sich die Situation oftmals aber durch Veränderung der Abstrahlrich- tung von Gitarrenverstärkern (z. B. weg vom Publikum, quer über die Bühne) sowie den Einsatz von In-Ear-Monitoring deutlich verbessern. (p.66)

	VOLUME (M3)	CAPACITY	T30(SEC)
1	655	300	2.2
2	785	500	1.6
3	890	350	2.5
4	1100	375	2.9
5	1420	375	3.8
6	1440	400	3.6
7	1600	500	3.2
8	1600	420	3.8
9	2080	700	3.0
10	2150	700	3.1
11	2540	525	4.8
12	3000	600	5.0
13	3050	450	6.8
14	3300	900	3.7
15	3800	700	5.4
16	3950	700	5.6
17	4500	1000	4.5
18	5400	700	7.7
19	5800	1430	4.1
20	6500	1200	5.4

Table 2 Objective differences between 20 Danish small and mid-sized indoor music venues discussed in (18). T30 is an indicator of the reverberation time. The same publication lists similar data for a further fifty venues across Europe.

In contemporary venues, on-stage floor monitors ('wedges' on account of their shape) enable musicians to hear themselves and each other. What can be heard through each of these loudspeakers (the 'monitor mix') is sometimes controlled from the FOH, but at larger venues, from a separate monitor mixing desk on the side of the stage. Level changes regarding these monitors always require a dialogue with the performers on stage as a certain volume level is often a necessity to perform. (During a show this dialogue usually relies mainly on gestures). Finally, DJs performing on stage work with loudspeakers to monitor their mix, often at very high levels and exposure to extreme sound levels and hearing damage in DJs is well documented (19). The risk of this group is often increased by the use of over-ear headphones that allow DJs to prepare, 'cue', the next track, inaudible for the audience.

4 Backgrounds to this review

4.1 Rules and regulations

4.1.1 Workplace

Music venue employees in most countries are subject to workplace health and safety regulations (WHS) (20, 21), however, compliance is rare (22-25). In some cases, it is argued that these laws don't necessarily cover musicians, sound engineering and other support staff (roadies, stage-hands, guitar-, drum- and keyboard- techs) because they are considered to be self-employed contractors. It is often pointed out that music venues are a special type of workplace – unlike the noisy industrial settings that the WHS laws were originally designed to address, in music venues the ‘noise’ is the central focus of the venue, rather than an unintended and unwanted by-product of an industrial process. Nevertheless, music venues are places of work and employees have the same rights as other employees to work in a safe environment.

4.1.2 Environmental noise regulations

In many countries, regulations that govern sound levels in music venues, bar a few notable exceptions (discussed below), are guided by environmental provisions to reduce impact and nuisance for immediate neighbours and those within a defined distance (in the case of outdoor concerts). Recent overviews of the different environmental noise regulations that cover music can be found in (1, 26). These environmental regulations are usually monitored using measurement protocols outside of a music venue, e.g. at the nearest wall of a neighbouring dwelling. At larger outdoor events it is now common practice to monitor sound levels on-site (usually at FOH) operating to maximum L_{Aeq} and or L_{Ceq} values that were derived using modelling and verified by stationary and or mobile measurement set-ups to comply with environmental regulation (27, 28).

With regard to outdoor events, there is a great deal of documentation outlining the heuristics, best practices and sound level measurement protocols from the perspective of acoustic consultants (e.g. (29, 30)), and government bodies (e.g. (27, 28, 31)). The impact of environmental noise regulation and enforcement on indoor music venues and their ability to operate is also well-known (see for instance a Music Venue Trust (UK) report into small music venues (32)). Well documented, and often cited in this context, is how in inner-city Sydney in the 1990s many small venues in bars and hotels had to stop hosting band concerts as a consequence of noise complaints from the influx of new neighbours attracted to gentrifying suburbs (33, 34).[6] To avoid a similar fate, strong lobbying from peak bodies and activist committees in Melbourne, a city with a great number of music venues, resulted in a planning rule usually referred to as *the agent of change principle* which places the burden of environmental noise reduction on new arrivals (neighbours, housing developments) (35). Also, in Australia, in Brisbane a different planning strategy was undertaken. Here the entertainment precinct was specially defined and exceptions to planning laws are allowed within its boundaries in order to accommodate and protect music venues (36, 37).

Strategies from local governments supporting venues sometimes result in financial support for venues to enhance sound proofing. While this is a good outcome for both neighbours and the sustainability of venues, pre and post measurements of these interventions are not necessarily conducted within the venues. An unintended consequence (although no data was identified to support this thesis) can be that with improved sound proofing the environmental noise exceedance is mitigated, but sound levels inside the venue go up and audience exposure increases. An example of a proposal to avoid this can be found in the 2018 White paper for the music peak body in Victoria (Australia). One of the action points lists:

[6] In the case of Sydney licensing changes around poker machines (‘Pokies’) provided an alternative, more lucrative, offering for venues.

Establish a program of matched grants for Victoria's music venues to update facilities to be accessible for people of all abilities, and for projects to help venues manage sound and enhance patron safety. [7]

In other words, when venues receive financial or in-kind support for sound proofing, matching grant funding could be allocated to perform pre and post measurements with regard to sound exposure. Ideally this would lead to a permanent installation of a SLMMM tool at FOH to ensure ongoing monitoring and management of sound exposure inside the venue.

A regulatory framework for sound levels in music venues informed by hearing health needs to learn from the many different approaches to, and problems with, environmental noise from music venues. On top of that, such a framework will need to operate in tandem with such environmental noise guidelines, as argued in (2).

4.2 Rules that benefit hearing health

A recent overview of global regulatory approaches and guidelines to SLMMM in entertainment venues with respect to hearing health, is presented in (2). Different to many environmental noise regulations, these regulations are enforced using measurement protocols within the venue, where audiences and staff are likely exposed to high sound pressure levels. Most of these rules and guidelines were introduced in the 2010s, and, irrespective of their success, one important change that has come about in the countries listed is that monitoring sound levels at FOH has become normal.

		Specified sound level limits				Other protective measures					
Country/ Region/City/ State	**Reference**	**Upper limit**	**Additional limit**	**Peak limit**	**Lower limit for <18 years**	**Provide warnings**	**Display level to operator/audience**	**Retain sound level data**	**Provide hearing protection**	**Provide access to rest area**	**Restrict access to speakers**
Switzerland[1]	Cercle Bruit (2018); Swiss Confederation (2012)	100 dB $L_{Aeq,60min}$	< 125 dB L_{Fast}		✔	✔		✔	✔	✔	

[7] https://www.musicvictoria.com.au/assets/2018/reports/White%20Paper%202018_website.pdf accessed 20 January 2020

Netherlands[2]	Vereniging Nederlandse Poppodia en Festivals et al. (2018)	103 dB $L_{Aeq,15min}$		< 140 dB $L_{C,peak}$	✔	✔		✔	✔		
Belgium – Flanders[1]	Departement Leefmilieu Natuur en Energie (2016); Flemish Government (2013)	100 dB $L_{Aeq,60min}$	102 dB $L_{Aeq,15min}$				✔		✔		
Belgium – Brussels[1]	Government of the Brussels-Capital Region (2017); Leefmilieu Brussel (2017)	100 dB $L_{Aeq,60min}$	102 dB $L_{Aeq,15min}$			✔	✔	✔	✔	✔	
Germany[2]	Deutsches Institut für Normung (2007)	99 dB $L_{Aeq,30min}$		< 135 dB L_{Cpeak}		✔	✔		✔		✔
France[1]	République Française (2017)	102 dB $L_{Aeq,15min}$	118 dB $L_{Ceq,15min}$		✔	✔	✔	✔	✔	✔	
Norway[2]	Norway (2011)	99 dB $L_{Aeq,30min}$		< 130 dB L_{Cpeak}					✔		
Austria[1]	Republic of Austria (2011)	100 dB $L_{Aeq,1min}$				✔			✔		✔
Sweden[1]	Sweden (2005)	100 dB $L_{Aeq,T}$ (<=5 hours/week)	115 dB L_{AFmax}		✔						
Czech Republic[1]	Czech Republic (2011)	100 dB $L_{Aeq,4h}$									
Italy[1]	Agenzia Nazionale per la Protezione dell'Ambiente (2001); Presidente del Consiglio dei Ministri (1999)	95 dB L_{Aeq}	102 dB L_{Smax}								
United Kingdom[2]	Health and Safety Executive	107 dB $L_{Aeq,T}$		< 140 dB L_{Cpeak}		✔					✔
Mexico[1]	United Mexican States (2013)	100 dB $L_{A,4h}$									
Nicaragua[1]	Republic of Nicaragua (2005)	110 dB L_{Amax}									
WHO	Guidelines for Community Noise (38)	100 dB $L_{Aeq,4h}$ (< 5 times/year)	110 dB L_{AFmax}								

Table 3 Adapted from (2) with permission from the authors. The superscript numbers 1 and 2 indicate whether this concerns 1: a law or 2: a not enforceable guideline.

4.2.1 Crowd Noise

The problem of enthusiastic, yelling, clapping, singing, screaming audiences is well illustrated by recordings of early The Beatles' concerts, but current-day examples rely on anecdote rather than documentation.[8] No systematic research into the contribution of crowd noise to the overall observable SPL and/or to the noise exposure of audiences has been identified. Indicative however is the German standard (4), which explicitly excludes "noises

[8] Michael Ebner from German SLMMM firm dbMess quips: "Teenagers at a Boy-Band group can easily add another 10dB.". In German: https://www.production-partner.de/story/10-jahre-din-15905-5/

caused by the audience” when measuring sound levels.[9] Similarly, several of the more common SLMMM systems provide functions to exclude crowd noise from the SPL measurement. For instance, by comparing the output signal of the FOH mixing desk (the electronic signal being sent to the PA) with the signal from the measurement microphone.[10]

Retrospectively, recorded measurement data can be analyzed by comparing C-weighted and A-weighted levels. Human vocal output generally doesn’t contain high levels of energy at low frequencies, whereas amplified live music does; C-weighted measurements are sensitive to these low frequencies, while A-weighted measurements are not. Consequentially when a song has finished the C-weighted SPL drops rapidly, and the concurrent A-weighted SPL can be interpreted as crowd noise).

As these examples indicates, two different types of crowd noise can contribute to the continuous equivalent sound level:

- applause and vocal response in between songs, and
- singing, clapping and yelling during songs.

4.2.2 Automating management of sound levels: limiters

In some of the examples in table 3 (e.g. Germany, Brussels and Austria), the requirement to monitor, manage and store sound levels at events becomes void when the sound system is equipped with properly installed and certified limiters to respond to sound level limit violations. This approach is common in bars or discos to comply with environmental regulations as it can reduce emission of sound into the immediate environment (39).[11] Some specialized limiters have the ability to filter out crowd noise from the program material, so the noise of an enthusiastic crowd does not drive the limiter.

Sound pressure levels in venues can be automatically tempered using peak-limiters. These are generally understood as a type of dynamic range compressor with a rate between 10:1 and ∞:1, and a threshold in the electronic signal path corresponding to a maximum SPL measured in (or outside) a venue. The peak limiter, or simply limiter, aggressively reduces the dynamic range of an audio signal by attenuating peaks in the amplitude envelope. Peak-limiting, in essence, alters the average value of the amplitude envelope expressed as the Root Mean Square (RMS). The effect of this process on both the loudness as experienced by audiences, as well as increases in noise dose, is insufficiently explored. When sound exposure reduction is the aim using peak-limiters to manage SPL can be counterproductive. In a situation where venue staff wants to ‘turn up’ and increase the volume control, the electronic signal is amplified before the limiter in the signal path. The limiter increasingly attenuates the peaks in the signal’s amplitude envelope and consequentially the RMS value of the electronic signal increases. With that increase in RMS the sound power emitted by the PA goes up and the perceived loudness, which is more closely related to RMS than to peak values, goes up with it. (40, 41).

What is unclear in this typical situation is the relation between the increase in loudness and the increase in audiences’ dosage and consequentially, their hearing damage risks. Furthermore, peak limiters introduce non-linear distortion, which potentially contributes to both loudness and noise dose. Exploratory work into the question whether small amounts of

[9] “Geräusche, die durch das Publikum verursacht werden”
[10] E.g. in SLMMM product Metrao (Metrao.com)
[11] For discos and events with DJs use of limiters may be more suitable than in concerts of live bands, given the usually limited dynamic range of pre-produced music.

intentional distortion applied to an audio signal can be used to increase perceived loudness at lower SPL is discussed in (42).

A different type of limiters designed for entertainment venues does not work by electronically modifying the audio signal, but rather by switching off (or cutting the power to) the amplifiers that drive the loudspeakers when a threshold is passed. Other models analyze and limit the audio signal in octave or even one-third octave bands.

A linear way of applying automated sound level control can be foreseen when the limiter, instead of modifying the amplitude envelope, controls the electronic gain of the sound signal before it reaches the amplifier. This can be done using a look-ahead function which is feature commonly available in the contemporary recording studio (i.e. Digital Audio Workstations or DAW), but given the real-time nature of live sound the associated latency is too great. However, when continuous equivalent levels (L_{eq}) are in use the longer integration periods can counter this problem. For instance, a special limiter on offer by a SLMMM firm in Germany takes the $L_{Aeq,\ 30\ min}$ from a sound level meter and responds slowly only when that value surpasses the maximum allowable dosage.[12] Rather than attenuating peaks this device controls the level of the electronic signal before it is sent to the amplifiers. As such is does not respond to short term peaks as they affect the L_{eq} relatively little.

A similar, but currently theoretical, approach using a prediction algorithm informed by $L_{Aeq,\ 8h}$ is proposed and simulated in (43). If feasible in the real world this could greatly improve the functionality of automatic sound level control in music venues, whether for real time control or by informing operators at FOH.

4.2.3 Monitoring/In-Ear Monitoring

One significant source of noise for musicians is their monitors. A monitor is a speaker that faces the musicians and allows them to hear clearly what the other members are playing. Musicians are often forced to increase their monitors' volumes to overcome the noise of the crowd or the monitors of the other members. Custom monitoring systems are available which put the monitoring speaker in the musician's ear and can therefore reduce the need for overcoming background noise. (44)

The use of floor monitors adds to the on-stage sound pressure level; for instance, for a drummer to hear a vocalist in their monitor it will need to compete with the acoustic levels produced by her drum kit. One study (44) used dosimeters on five members of a band, as well as one spectator. Data recorded during one rehearsal and one concert revealed that the exposure of the band members was much higher than the exposure of the spectator (there was no indication where in the venue (described as 'a local nightclub') the spectator experienced the concert, and how far away from the stage.

The floor monitors are commonly placed on stage with the directional mid and high frequency loudspeaker drivers aimed at the performer's ears (hence the wedge-shape). From a sound system design and optimization perspective this is not ideal as the sound from the monitor re-enters the system (e.g. through a vocal microphone) reducing the quality of the signal as unwanted, strong reflections (45). Furthermore, for low and low-mid

[12] https://dbmess.de/limiter-lim1.html

frequencies the monitor loudspeakers function as omnidirectional sources, emitting unintelligible (or 'muddy') low frequency sound into the auditorium (for an example see (46).[13] Consequently the levels addressing the audience in the auditorium will need to go up (at least for the higher frequency bands). Similarly, the PA loudspeakers aimed at the auditorium are usually positioned close to the stage, as such adding to the sound level on that stage, which makes it harder for musicians to hear what they need to hear (47). Since the 1990s this chain of events has been broken by the use of portable audio receivers with in-ear monitors (IEM) (48). Even though these personal monitor systems are often used in combination with the traditional floor monitors or side-fills, the on-stage levels can commonly be brought down. Consequently the 'bleed' from the stage into the auditorium is reduced and when operated with due consideration, this can result in a reduction of the levels addressing the audience.

Two studies have evaluated the use of IEM, looking at users' exposure when compared to floor monitors (49, 50). Both studies agree that IEMs can contribute to a reduced sound exposure of musicians on stage however awareness and guidance are required as well as in-the-ear sound level measurements to inform users about their exposure. Without training or consultation musicians are likely to use IEM at the same, or higher, sound levels they are accustomed to from floor monitors, which would undo any possible reduction of their exposure. Another study considered how the use of IEM affected the players' ability to make music (51). While for instance intonation was easier using IEM over using floor monitors, subjects reported a level of detachment from the environment on stage. As a consequence of that latter outcome not all musicians may choose to perform using IEM.

5 Ecological research into SLMMM

Establishing the efficacy of SLMMM in the ecology of a music venue is methodologically challenging. Very few parameters can be fixed making it virtually impossible to design reliable experiments. At the same time, in order to improve conditions in music venues it is important to create an evidence base, however limited, that can inform and support future guidelines. There are several studies using dosimeters to investigate audience exposure at concerts and festivals. (21, 22, 52) What is often left unexplored in such studies is the question how the observed exposures relate to the SPL in the venue as measured for instance at FOH where, crucially, decisions about the sound level are made.

5.1 Monitoring Tools

Given the growing number of countries that require SLMMM at FOH there is an increasing range of products available, both as software and hardware, that perform the measurements and present the actual SPL to the operator in a variety of integration times, L_{eq} values and weightings. Some of the interfaces (e.g. 10EaZy, Metrao) provide a traffic light system with a number of green and red segments that indicate how much of the L_{eq} limit is left with respect to the current level or how much reduction is required to get the level back to within that L_{eq} limit. Other interfaces (e.g. WaveCapture RC3) provide a time/dosage remaining as a value

[13] In the German DIN norm loudspeakers on-stage (guitar-amps, floor monitors) are included in the sound system under test; unamplified sound, in a direct acoustic path to the audience is excluded(!) [DIN 15905-5 : 3.313]

or a percentage. In Appendix [B] a number of screenshots are provided showing different approaches to the SLMMM interface.

5.2 Melbourne

In a study in Melbourne (53, 54) the approach to counter the methodological challenge was to increase the sample size. Over 2016-2017 data was collected for several weeks in six urban, small, indoor music venues using a commercially available SLMMM tool (laptop, calibrated interface and microphone, software (55)). The tool was used to collect data each night that a band played in the venue, but the operators did not have access to the SLMMM interface. In a second phase of a similar number of nights, the system continued to collect data but now giving FOH operators access to real time data and a traffic light warning system based on an upper limit for the acceptable $L_{Aeq,\ 15min}$ (which was chosen by the venue team in a discussion with the researchers).

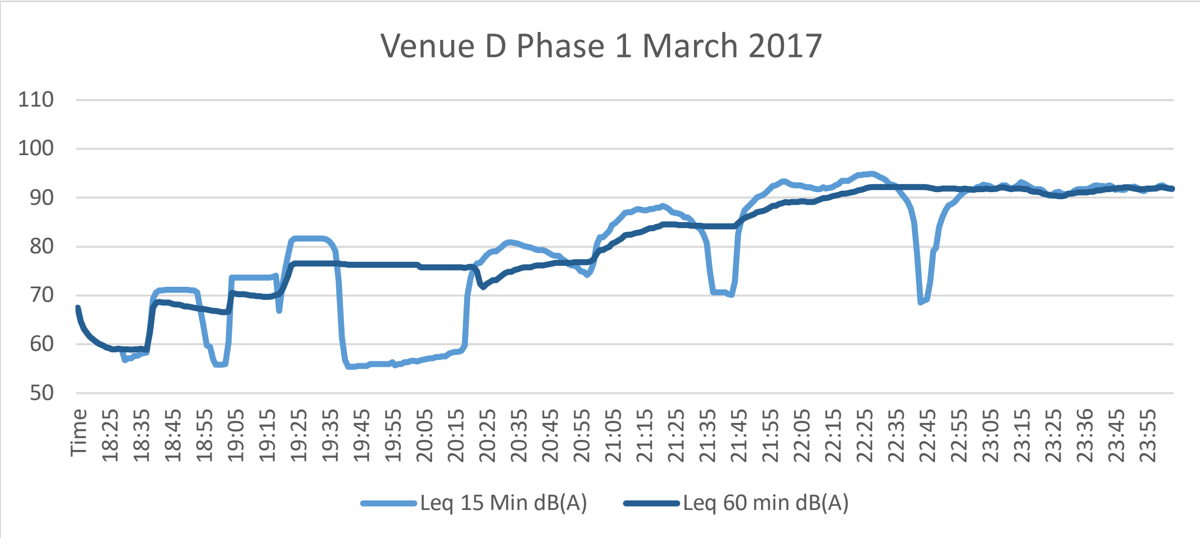

Figure 2: Example from Melbourne study Phase 1 (no real time data display). This is a typical band night with three different sets. Soundchecks can be observed between 18:30 and 19.30 followed by three sets before 22:45, finishing with a DJ set (or house music). The levels can be seen going up over the course of the night, which is something that can be observed regularly at concerts. Also note the difference in response time between the two integration times, the 60 min graph gives a good indication of the sound exposure over the whole night, the 15 min graph shows more clearly whether the sound dosage is increasing or decreasing.

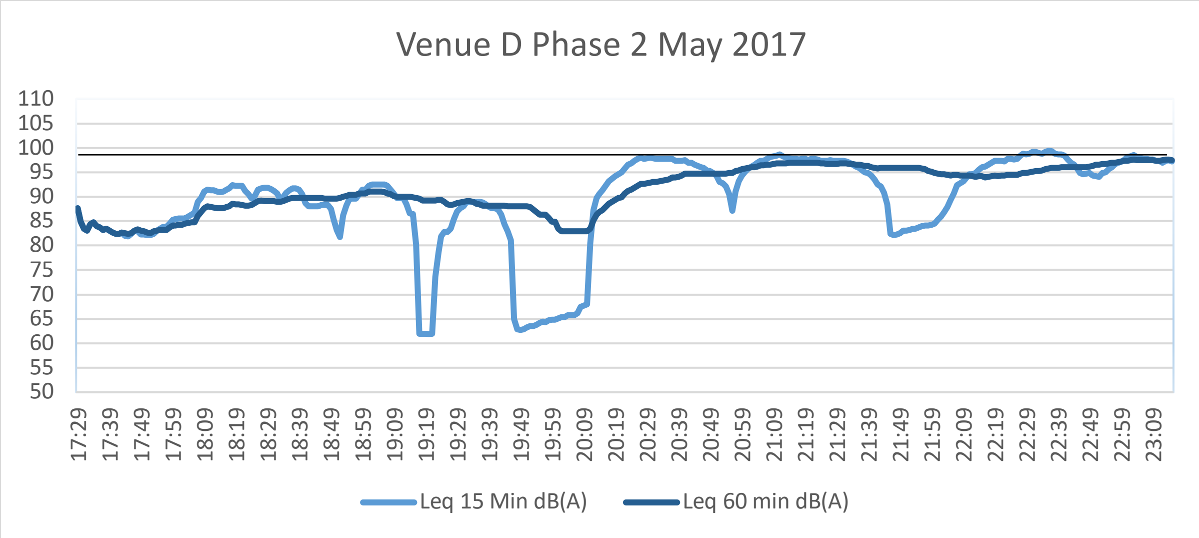

Figure 3: Example from Melbourne study Phase 2 (real time data display available to operator). A similar night with sound checks until 19:45 and three sets between 20:15 and 22.45. This graph illustrates the leveling effect that is sometimes observed, around the set limit of $L_{Aeq,\ 15min}$ = 98dB (black line). For this night the system reported 5 exceedances for a total of 24 minutes spent above the limit.

Keeping the methodological challenges in mind the Melbourne study concluded that with the use of such an interface, excessively loud nights several dB over the set maximum level can be avoided. At the same time a levelling effect as a consequence of this approach was observed (but not as a significant outcome): operators tend to approach the maximum level as a target. That is to say, loud concerts were avoided, but concerts that would ordinarily be quieter were in some cases mixed at a louder level.

To corroborate the data collected by the system at FOH dosimeters were placed around the venues on one night in each of the two phases.

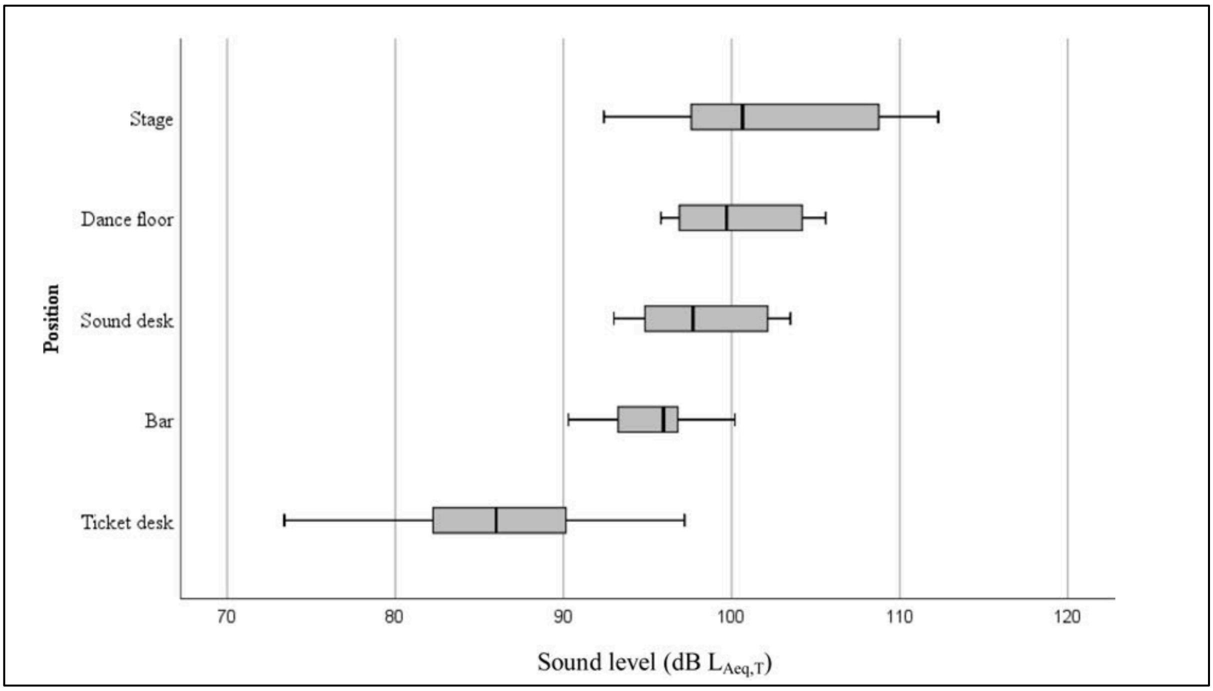

Figure 4 From (54): dosimeter readings from two nights each in the six urban venues in Melbourne (2017/18)

Even when considering the limitation of positioning stationary dosimeters in a working music venue, a revealing picture emerges (fig. 2). In these smaller venues the highest SPLs can be observed on stage (extremely high peaks, L_{Cpeak} > 140dB, were measured on the stages of two venues), often creating a greater exposure to musicians on stage than patrons addressed by the PA system.

5.3 Chicago

The levelling effect alluded to in the previous example was a point of departure for a study replicating the approach taken in the Melbourne venues at an outdoor setting in Chicago (56). This project collected data at a three-day festival with alternating performances on two largely similar stages Red and Green (this allows for change-overs on one stage while a performance goes on at the alternate stage). FOH operators for the Red stage had access to the SLMMM interface (the same software as used in the Melbourne study, now set-up with a $L_{Aeq,\ 5min}$ limit) while FOH operators of the Green stage did not. A 2 dB reduction in $L_{Aeq,\ 5min}$ was observed at the Red stage where FOH operators followed visual cues from the SLMMM interface; however, due to various limitations in the study, it is not possible to unambiguously attribute this reduction to the presence of the SLMMM interface.

The dynamic range (using L10-L90 based on $L_{Aeq,\ 1sec}$) was analysed for all performances on both stages to see whether the levelling effect could be observed. Again, no statistically significant outcomes emerged but a reduction in dynamic range (which could be caused by a levelling effect) was suggested at those concerts where the SLMMM interface was in use.

5.4 Lab study using Loudness Metering

The levelling effect also emerged in a small exploratory study (57). The program-loudness of a FOH mix was derived in two situations, with and without visual access (for the operator) to a Loudness meter. Typical live sound mixing set-ups don't include ITU-R BS.1770 Loudness meters that are now common in audio broadcast and streaming. For this study a Digital Audio Workstation (DAW) was linked to the output of the FOH mixing desk and calibrated to L_C=73dB. Data was collected during a number of performances of the same band, with and without access to the loudness meter. The authors argue that access to a visual interface detailing continuous equivalent level or in this case loudness units decreases the dynamic range. The conference paper reporting this study does not address methodological shortcomings, but is worth mentioning here as this approach using loudness metering could readily be implemented in other studies.

5.5 Norway

In Norway a large-scale data logging project has been underway since 2017, instigated and provided by the MUO (now Kulturrom) music peak body. Circa 115 (as of February 2020) associated permanent music venues have been equipped with a class 1 calibrated measuring microphone and a computer using a SLMMM tool positioned at FOH.[14] Even though not all recorded data is complete and not all venues successfully monitor and record every concert, this is by far the largest dataset available at the time of writing. The project also includes a survey collecting physical and acoustical data of each venue as well as standardized audio sweeps (recorded sine waves sweeping through all relevant frequencies) recorded through the SLMMM system.

An early overview of the collected data until mid-2018 is presented in (58). The paper reports on the progress of the project and lists some specifics, including what data is retained and the option for venues to choose between two level limit options:

- $L_{Aeq,\ 15min} \leq 102$ dB, measured using a sliding 15 min time window
- $L_{Aeq,\ 30min} \leq 99$ dB, measured using a sliding 30 min time window

The key targets for the project are listed as:

- To survey sound levels at permanent venues for amplified music
- To reduce the sound levels on a long-term basis (the industry needs to able to document that such a reduction is actually happening).
- Make concert promoters and the technical manager of the venue more conscious about controlling the sound levels

Of note in the preliminary results (58) is that a significant number of data sets report $L_{Aeq,\ 15min}$ just below or at 102 dB, which again hints at a levelling effect when operators at FOH have access to real time SPL data from the SLMMM interface. The authors suggest two explanations:

[14] Wavecapture RT3, which offers a different interface: rather than the traffic light system it indicates the remaining L_{Eq} dosage at the current level (with respect to the set L_{Aeq} value).

> It is interesting to note that a significant part of the concerts have maximum levels at, or just below the 102 dB warning level. This might indicate that sound engineers "aim for" the warning level when mixing a live concert. Another explanation might be that the sound engineers consider an equivalent level of approximately 101 dBA to be desirable for pop and rock concerts. (58)

This resonates with a remark in (18) with regard to the highest of the limits (in The Netherlands) listed in table [3], $L_{Aeq,\ 15min}$ = 103dB: "…even with the right to be at 103 dB, most shows are played at 99-101 dB on average" (p. 24). However, from the three venues in the Melbourne study (54) that chose a $L_{Aeq,\ 15min}$ = 103dB setting for the SLMMM interface, only one performed predominantly in the 99-101 dB range on average while the other two operated at higher levels, up to $L_{Aeq,\ 15min}$ = 104dB. Further analysis of data from Norway or the Netherlands (where data collection became mandatory and centralised in 2018) will show whether this claim can be supported by data. Caution is also required as these large data sets (e.g. from Norway or the Netherlands) contain readings from a wide range of venues – small, large, indoor and outdoor. Furthermore, in absence of strict protocols, measurements are usually taken at FOH which may be nearer or further from stage depending on each venue.

6 Discussion

The questions listed at the start of this report will be discussed in this section.

6.1.1 What are the commonly implemented sound limits?

Table 4 shows the sound limits currently in effect. The dB values appear to be on or around the WHO guideline of $L_{Aeq,\ 4hours}$ = 100 dB. (38) However, it is important to keep in mind that the same dB limit has quit different implications depending on the integration time. The maximum of five events per year that is tied to this current WHO guideline is not explicitly mentioned in any of the examples. This raises questions for instance about multi-day music festivals, when perhaps three days' worth of exposure is experienced in as many consecutive days. The most thorough regulations and guidelines include provisions for awareness, including clearly advertising that dangerously high sound levels can be expected, earplug availability (for free or at cost) and preventing access to areas right in front of loudspeakers.

In several countries (including Norway and the Netherlands) regular reporting is mandatory and data is collected centrally. In the Netherlands the data is collected anonymously to determine whether in general the limits are followed. In Norway a great deal of data and metadata are collected, including running levels in 1/3 octave bands and audio recording to detect interference from audience noise.

Country/ Region/City/ State	Specified sound level limits			Specifications			
	Upper limit	Additional limit	Peak limit	Measurement Location	Location at which a correction factor is applied to estimate exposure	SLM Class	Documentation requirements/retention period
Switzerland	100 dB $L_{Aeq,60min}$		< 125 dB L_{Fast}	FOH	loudest spot in audience area[15]	2	6 months
Netherlands	103 dB $L_{Aeq,15min}$		< 140 dB $L_{C,peak}$	FOH	In preparation[16]	2	Reports collected centrally (anonymous)
Belgium – Flanders	100 dB $L_{Aeq,60min}$	102 dB $L_{Aeq,15min}$		FOH	n/a	2	30 days
Belgium – Brussels	100 dB $L_{Aeq,60min}$	115 dB $L_{Ceq,60min}$		FOH[17]	loudest spot in audience area	2	30 days
Germany	99 dB $L_{Aeq,30min}$		< 135 dB L_{Cpeak}	FOH	loudest spot in audience area[18]	2	
France	102 dB $L_{Aeq,15min}$	118 dB $L_{Ceq,15min}$		Loudest spot in audience area			6 months
Norway	99 dB $L_{Aeq,30min}$		< 130 dB L_{Cpeak}	FOH		1	Collected centrally
Austria	100 dB $L_{Aeq,1min}$			FOH	loudest spot in audience area		
Sweden	100 dB $L_{Aeq,T}$ (<=5 hours/week)	115 dB L_{AFmax}		FOH	loudest spot in audience area		
Italy[1]	95 dB L_{Aeq}	102 dB L_{Smax}			loudest spot in audience area, 1.6 +/- 0.1 meters above floor	1	
United Kingdom[2]	107 dB $L_{Aeq,T}$		< 140 dB L_{Cpeak}		in all areas accessible to audience		

Table 4 Measurement prescriptions, adapted from (2)

[15] In German: Die Grenzwerte müssen am lautesten Ort auf Ohrenhöhe eingehalten werden. Dieser Ort wird Ermittlungsort genannt. Da eine Messung am Ermittlungsort nicht immer möglich ist, kann der Schallpegel auch an einem anderen Ort, beispielsweise beim Mischpult, überwacht werden. Dazu muss jedoch vorgängig die Schallpegeldifferenz zwischen Ermittlungsort und Messort mit rosa Rauschen bestimmt und schriftlich festgehalten werden..

[16] In the Netherlands a detailed measurement protocol with relevant correction procedures is in preparation, Marcel Kok from dBControl is preparing an advice for the covenant partners (May 2020).

[17] The microphone shall be placed in a position that is representative for the exposure of the audience. An enforcement measurement can take place anywhere in the audience, between 1.2 and 1.5m above the floor.

[18] Maßgeblicher Immissionsort: der für die Beurteilung der Lärmimmission dem Publikum zugängliche Ort, an dem der höchste Wert des Schalldruckpegels ohne verfälschende Störsignale erwartet wird. Verfälschende Störsignale im Sinne dieser Norm wären beispiels- weise durch das Publikum erzeugte Geräusche (unter anderem Applaus, Gesang) sowie Geräusche direkt aus Musikinstrumenten (vor allem Schlagzeug).

6.1.2 What is the evidence on the use and implementation of sound limits in entertainment venues?

The number of studies is small but it appears that sound limits can help reducing the sound dosage that audiences are exposed to. Two reports (3, 59) mention that improvements in technology (e.g. line arrays, in-ear monitors) and increased professionalization of sound engineers helps achieve the limits at least in larger venues. Some larger datasets are becoming available (e.g. Norway, Netherlands) and pilot projects are trialling ways to analyse the data. From data collected when SLMMM is displayed to operators it appears that in the majority of cases, limits set at FOH are followed (29, 54, 56, 58, 60). However from the Melbourne study in Australia (where no limits with regards to audience exposure are specified despite early efforts by Pam Gunn (61)), we found that when a voluntary limit is specified, sound levels can still exceed the limit set. Buy-in, as well as competence, from FOH operators to effectively act on the information provided by the SLMMM interface is crucial. A problem that potentially affects all venues is the levelling effect that may be evident when SLMMM systems are in use. Work is needed to improve SLMMM interfaces in ways that allow operators to ensure that sound levels remain below the appropriate limit while avoiding any tendency to treat the limit as a target.

A very recent publication (62) details random sampling from a number of different urban venues with $L_{Aeq,\ 60min}$ ranging from 103 to 120 dB. An apple iPhone with a specialised external measurement microphone was used, which should be reliable for noise survey work (63). However, the paper lacks detail in microphone placement (free-field, body-warn, on a table, etc.) and calibration (i.e. was the set-up recalibrated before every measurement?). This study would suggest that recommended sound exposure limits are likely routinely being exceeded in urban venues at present, however the uncertainty about the measurement protocol and calibration means that these data must be interpreted with caution.

Although further study is required, what is emerging is that the challenges are greater in smaller indoor venues. This is a problem because even though audience sizes are relatively low, many city dwellers regularly attend concerts in small indoor venues. For instance, the Melbourne Music Census (64) from 2017 cites more than 100,000 patrons attending concerts in small urban venues on Saturday nights. Although Melbourne has an exceptionally large number of small urban venues (>500) this suggests that total entertainment sound exposure in small venues might be larger in terms of patron number than from large outdoor festivals. In these smaller venues two problems emerge: levels for louder genres (punk, rock, i.e. with loud guitar amps and drumkits on stage) tend to be very high and harder to control as a consequence of the room size, but also the on-stage levels of backline (guitar amps) and drumkits. Additionally, in such venues keeping people away from the loudspeakers is harder and ‘flying’ modern loudspeaker systems (e.g. line arrays) from the (usually lower) ceilings is not always possible or financially achievable.

6.1.3 What is the current evidence on sound measurement in venues?

Particularly through the work done with regard to environmental noise emissions there is a lot of experience with firms (e.g. dBcontrol, dBmess (3, 29)) and products (10EaZy, Metrao, WaveCapture RC3, see Appendix A. Given that control over sound levels, whether considering audience exposure or environmental noise emission, is centralised at FOH, such experience can readily translate between the two domains. Similarly, the software products listed can be applied to manage audience exposure and environmental noise emission simultaneously.

In smaller venues where venue staff is involved in for instance stopping and starting measurements, or setting-up non-permanent measurement set-ups, problems can occur. For instance the paper detailing from the Melbourne study (54) mentions that in participating venues the motivation of a team to participate influenced the data collection: “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.” The paper then lists another challenge, no every concert in a venue is mixed by an in-house engineer, often bands bring their own engineer. These, from the perspective of a venue, guest engineers, not necessarily have the familiarity with SLMMM systems, or sometimes lack the motivation to help reduce audience exposure.

6.1.4 How are sound limits enforced by government authorities?

Regimes vary from country to country. In general employees are covered by WHS regulations which may have its own regime. Inspections are sometimes carried out by health officials (e.g. environmental, WHS) sometimes by law enforcement (e.g. in Flemish Belgium). In Germany the standard is not enforced but provides a framework for event promotors to demonstrate compliance after the fact. In the Netherlands the hearing covenant assumes voluntary compliance, the current version (2018) will be reviewed on the basis of the reported sound levels, as centralised data collection is now included. For outdoor events, enforcement of environmental noise is sometimes done through licensing, planning provisions and monitoring and recording during the event. Exceedances in the recorded levels, as well as missing curfews can sometimes lead to fines, however this relies largely on anecdotes.[19] From a perspective of enforcement, obtaining measurements within a venue that will stand up in court is problematic, particularly with the longer L_{Eq} periods because the officer has to witness the measurement from start to end. A different approach to evidence provision – where venues are required to record levels for each and every concert might help, but this could encourage measurement tampering (e.g., placing nail polish on the measurement microphone, moving the microphone to a quieter position etc). Ebner (3) mentions that enforcement is stricter in Switzerland, but no evidence was found in the context of this review. In Switzerland enforcement is delegated to the Cantons, and implementation can vary accordingly.

In the commentary on DIN 15905-5 from 2009 (4) a chapter on German jurisprudence is included. In Germany the DIN standard is a technical rule; whereas the applicable law originates in from the responsibility for the safety of others, the so-called ‘Verkehrssicherungspflicht’. A literal translation of that term would suggest a connection to traffic regulation but this is not the case. The heart of the matter is that if you install or operate a source of danger (‘Gefahrenquelle’) you are responsible for the safety of those exposed to that danger. Claimants (e.g. with hearing damage after a concert) would need to prove causality between their hearing loss and the exposure to high sound levels at the concert. When in this situation those responsible have not measured and documented the sound levels, the burden of proof is reversed; now the organisers will have to prove that there is no causality between that event and the claimant’s hearing damage.[20] The commentary then discusses six examples of German court cases between 1992 and 2002.

[19] See for instance for some high-profile examples: https://www.telegraph.co.uk/culture/music/rolling-stones/9703179/Fans-cant-always-get-what-they-want-bands-caught-out-by-curfews.html [accessed January 2020]

[20] Irrespective of the existence of a guideline or law, a common-sense approach for concert promoters would be to pay for a specialist consultant to document sound levels during a concert, even more so for concerts attracting underaged audiences.

In a 2017 blog post evaluating the ten years after the introduction of the DIN standard the same author mentions that most court cases are settled outside of court (3).

A Swedish paper (65) details official inspections (in 2005) of sound levels at concerts that were either announced or unannounced, at the discretion of the municipality. Surprisingly there was hardly any difference in the number of recorded exceedances when comparing announced (23%) and unannounced (21%) inspections (of all venues including cinemas and gyms). In a few of those cases municipalities handed out infringement orders, sometime with a fine attached (n=undisclosed). At festivals and concert events 42% of inspections revealed exceedances of the highest recommended SPL, which in Sweden is $L_{Aeq,T}$ =100 dB, with a maximum of 5 hours per week. With regard to the measurement protocol a question arises: do inspectors need to measure and record SPL for the duration of the entire concert (T) or is extrapolation from a shorter L_{eq} period allowable? The Swiss ordinance allows for shorter measurements (than 60 minutes) when the limit is clearly exceeded.[21] The problem of unannounced, covert measurements, in particular of longer duration emerged from evaluations in Belgium (59). With a 60 minutes L_{eq} period, an hour of observed measurement must pass to determine whether the level complies or not. A further issue is crowd noise, with audience members, intentional or not, yelling into or in proximity of the measuring microphone. And finally, given the long duration of the measurement it is hard for inspectors to go unnoticed and operators may choose to, if they indeed can, bring down the level once made aware of the presence of an inspector.

6.1.5 Is there information on A- and C-weighted limits?

The A-weighting is adapted from the equal loudness curve at 40Phon, as such taking the specific sensitivities of our hearing into account. As a continuous equivalent decibel value, the A-weighting is the most common objectified parameter in any regulatory framework regarding hearing. The question whether this is the most useful weighting when it comes to live music entertainment at sound levels much higher than 40Phon has been raised in many publications. St. Pierre and Maguire (66) from 2003 provides an overview of reported issues with the A-weighting. With its bias towards the mid/frequency range the A-weighting remains a good indicator of loudness, the question is whether it is as good an indicator of hearing damage risks, when it is not considering the lower end of the frequency spectrum?

The evaluation from Flemish Belgium (59) suggests that for the venues' perspective a L_{Ceq} value is desirable.[22] The C-weighted decibel is increasingly recognised as the most appropriate measurement to evaluate environmental noise emission of (outdoor) concerts and festivals (27). A practical consideration can be found, as argued in the Swiss study (67), in the case of correction measurements between FOH and closer to the stage: it is the low frequency component that causes the greater variance. When many different genres (with different typical spectra) are performed in one venue, correction measurement should be made for every different band. From that perspective using the C-weighted decibel (or even third octave band using dBZ as in the Chicago study) might prove to be more appropriate.

[21] Bei einer deutlichen Überschreitung des Grenzwertes kann die Messung auch früher beendet werden, wenn rechnerisch gezeigt werden kann, dass der Grenzwert für den Stundenpegel nicht mehr eingehalten werden kann.

[22] Het inkorten van de meetduur is een vaak terugkerende vraag, evenals het toevoegen van de C-weging, dan vooral als beperking van de overlast naar de omgeving. (p. 119)

To illustrate, the French body that prepared the recommendations (Haut Conseil de la santé publique, HCSP) (68) for the French legislation (2018) discusses a number of publications that assess the hearing damage associated with low frequency noise:

> This report shows that exposure to low frequencies has increased in recent years; at too high levels, these cause hearing loss, especially at higher frequencies. This point is integrated into the recommendations […][23]

They conclude that L_{Cpeak} can be used to assess this, recommending a limit of L_{Cpeak} = 120dB;

> The HCSP recommends retaining the joint use of these two measurements, the A weighting being suitable for average measurements over fairly long times, the C weighting being used to measure peak levels during impulse noise.[24]

Ultimately the French regulation did not include a L_{Cpeak} value, but did specify a continuous equivalent C-weighted level, $L_{Ceq,15min}$ =118dB (while $L_{Aeq,15min}$=102dB). The peak value proposed by the Haut Conseil de la santé publique was lower than for instance in Germany (L_{Cpeak}=135dB) or The Netherlands (L_{Cpeak} = 140dB). The 140dB maximum value for C-weighted peaks is cited in many occupational health and safety regulations and appears to originate from North-American standard ANSI 3.28 (1986), which in turn informed ISO1999 (1990) (69). As discussed in the Chicago study (1, 56) audiences directly in front of subwoofer systems (often placed in an array in front of a stage) are at risk of exposure to peaks near or over 140dBC. One recommendation from (4) is to control C-weighted peaks with limiters. Peaks greater than 140dBC were also detected in on-stage dosimeters in the Melbourne study (54) demonstrating the urgency to consider the impact of musicians on their fans' hearing and also their own.

6.1.6 Should average, maximum or both limits be applied? How long should the measurement be?

Except for the German standard, which assesses blocks of 30 minutes to derive the L_{Aeq}, most documents listed in table 3 assume a sliding average, i.e. the L_{Aeq} is recalculated with each measurement (e.g. every second). Although nearly all the specified L_{Aeq} limits are set around 100dB, there are differences in the prescribed integration period, from the full duration of the event down to 15 minutes. From current practice we learn that L_{eq} values are most useful as they relate directly to dosage, for audiences and indirectly to neighbours. They are much easier to use for operators in comparison to fast and slow SPL averages that were used as limits in the past.

Anecdotally, operators prefer a five or even three-minute L_{Aeq} value to be displayed on the SLMMM interface (e.g. the Chicago study used $L_{Aeq,5min}$), as this is more in-line with the length of the average pop song. Furthermore, an exceedance of $L_{Aeq,60min}$ takes much longer to 'recover' from i.e., it takes relatively long for the L_{eq} to drop with respect to the duration of

[23] Le présent rapport montre que l'exposition aux basses fréquences a augmenté au cours des dernières années ; à des niveaux trop élevés, celles-ci provoquent des pertes de sensibilité auditive, en particulier à des fréquences plus élevées. Ce point est intégré dans les préconisations faites ci-dessous. (ibid p.26)

[24] Le HCSP recommande de conserver l'usage conjoint de ces deux mesures, la pondération A étant appropriée à des mesures moyennes sur des temps assez longs, la pondération C permettant de mesurer des niveaux crête lors de bruits impulsionnels. (ibid p.26)

a performance. As such, an exceedance by the support band could for instance impede the allowable sound level for the headliner, or the next band on stage.

In Flemish Belgium operators are helped by having not one single limit, but a combined short (15 min) and long (60 min) integration time. As a rule of thumb, within one measurement the difference between maximum values in a 60 minute and a 15 minutes L_{Aeq} is considered to be circa 2dB.[25] This difference is applied in the rules from Flanders where both $L_{Aeq,\ 60min}$=100dB and $L_{Aeq,\ 15min}$ =102 need to be complied with. The 15-minute secondary value is to be understood as extra headroom during the loudest part of a concert (29). However elegant this approach is, according to an evaluation (59) from 2015 this can lead to confusion with operators relying solely on the higher value and so gaining this extra headroom for the duration of the entire concert.

That evaluation also indicates that according to feedback from law-enforcement the 60-minute integration time is too long to make unimpeded measurements, and consequentially measurements are not always completed.[26] It is challenging to perform an observed measurement in amongst the audience and those charged with taking these measurements for enforcement purpose have expressed the desire for a more straightforward and faster approach.

6.1.7 What class of device is normally used for measurement

In general IEC 61672, Class 2 is accepted but it is important to notice that external specialists or enforcement officials are likely to use IEC 61672 Class 1. Given the many parameters that can play a role (acoustics, audience noise, position) it is not clear whether the modest increase in accuracy of class 1 is required, nor whether the additional cost is warranted. However, discrepancies between measurements at the same event with sound level meters of different accuracy can potentially lead to ambiguous outcomes.

Mobile Sound Level Meters should be calibrated before and after measurements (e.g. as in the German DIN norm). In-situ devices should be calibrated regularly, as well as verified when an inspection is taking place. In practice that means when external specialists or enforcement officials attend a concert for an observed measurement the calibration of the in-situ sound level meter is verified using the same calibration procedure as for the mobile device.

6.1.8 Where does the measurement take place?

The different examples of existing regulations and guidelines (see table 4) come with varying levels of prescriptiveness when it comes to measurement protocols. FOH is the most practicable position but for instance the distance from FOH to the stage can vary greatly per venue, making between-venue assessments rather problematic. A cue can be taken here from

[25] The precise difference varies with the dynamic and spectral content of a music performance.
[26] From (59): Men heeft vooral problemen met de meetduur van 15 minuten en 60 minuten die als te lang wordt beoordeeld, de meetplaats midden in het publiek en de dubbele normering met een toetsingswaarde en een limietwaarde. Voor de grote meerderheid is het uitvoeren van een correcte meting niet evident, waardoor het meten vaak vermeden wordt. Een eenvoudigere en snellere manier van vaststellen bij de handhaving in de praktijk is bij velen gewenst.(p. 119)

environmental noise practice, as discussed in (26): “measurement locations are more precise when cities develop their own regulations”. Venues, just like cities, are all different and to find the most appropriate location requires local knowledge.

According to the Melbourne study, in small indoor venues, FOH levels can be lower than audience levels (table 4). The question that arises from these studies where SPL measurements are conducted at FOH is, how well do those data represent audience exposure? A similar question could be asked in relation to the limits in Flemish Belgium and The Netherlands because in these cases, the measurement at FOH is not corrected to reflect a position that is more representative of audience exposure.

The Chicago study (56) gave further insight into the exposure of patrons immediately in front of the stage who are exposed to very high sound levels. Peaks ($L_{C,\ peak}$) just below 140 dB were registered, and the authors raised the problem of positioning arrays of powerful sub-woofers (reproducing the spectral content below 80Hz) in front of the stage as opposed to flying them with the main PA to the left and right of the stage. This study used baseline third-octave measurements (taken the night before the first festival day) of pink noise in 16 locations in the audience area. Using these baseline measurements, the correction factor required from the FOH levels can be modelled for different spots in the audience area.

An older paper discussing research at a Swiss outdoor festival (67) indicates that the difference between levels measured at FOH and at the loudest spot in the audience, directly in front of the loudspeakers can be as large as 13.3dB, and a correction measurement is required (as prescribed in several of the examples in table 4). The study took measurements at FOH and near the stage, as well as gathered data from dosimeters worn by volunteers (n=33) attending the festival. The paper reports that the correction factor (‘compensation’ is used in the paper) varied by as much as 8 dB (+/- 2.3 dB) across nine different performances: “It varies as a function of the meteorological conditions, local topography, the number of visitors, and is particularly dependent on the spectrum of the music and the proportions of high and low frequency sounds.”.

A study (70) following volunteers at a Danish multi-day festival using specifically configured behind the ear hearing aids, observes “good correlation” between L_{eq} recorded at FOH (uncorrected) and the data gathered from volunteers in the audience. The study suggests that measurements taken at FOH can be used as: “a guideline for the SPL that the sound engineer exposes the ears of the audience to”. A limitation of this approach, addressed in a later paper (71) is the need to compensate for the presence of head and torso, which should be a consideration for measurements using body-warn dosimeters too.

A study at two outdoor festivals in Norway (60, 72) shows that SLMMM informed by environmental regulations can help reduce exposure to loud sounds. Patrons (n=8) were fitted out with dosimeters at two different music festivals, one in an urban area, governed by local environmental regulation, and one in a rural setting without any enforced environmental noise conditions. At the urban festival, levels stayed within both the national as well as the WHO guidelines, at the rural festival levels exceeded both. This suggests that SLMMM for environmental outcomes can help reduce audience exposure. Once more, this study concluded that FOH measurements can reliably predict audience exposure. As before this brings questions about the relation between body-worn dosimeters (within the audience area) and free-field measurements at FOH. Interestingly, the correlation between FOH measurements and body-worn dosimeters has so far only been observed at outdoor events, not in indoor venues. On the contrary, the small venue study in Melbourne found great variation in dosimetry between different areas in a venue (fig. 2).

6.1.9 How often should the measurement be done?

Measurements should be ongoing, providing real time feedback to FOH operators during events. For instance, in many cases levels can be changed at any moment by the turning of a knob (on a guitar amp) or the pushing of a fader (on a mixing desk) therefore it's important to continuously measure the sound level. Similarly, providing real-time feedback allows the sound engineer to act on any level excursions and bring levels back within recommended limits (where possible). Finally, measurement data should be stored and if feasible collected centrally. This can be done to keep tabs on compliance within a relevant administrative region.

6.1.10 Who is normally doing the sound measurement?

At larger (outdoor) events this is usually done by specialised Sound-guarding companies (e.g. dBcontrol in The Netherlands and Norway, dBmess in Germany, and Eventacoustics in The Netherlands). Environmental policing bodies and indeed policy can train agents to perform reliable measurements. In permanent venues this is usually house staff, working with a (permanent) set-up at FOH. At the moment there are no governing bodies or compliance schemes that certify operators to perform measurements. And, at the same time level of training and education of those employed as live sound engineer varies greatly, with a survey in the UK from 2015 reporting 63% of n=230 respondents without formal education in audio engineering or music technology. (73) It remains to be seen whether those tasked with SLMMM are suitably informed with regard to the use of decibels and continuously equivalent sound levels. And similarly, understanding how to for instance properly check and calibrate the measurement equipment, and how measurements may be affected by location, proximity to nearby surfaces, crowd noise, etc.

7 In Conclusion

Sound pressure levels in music venues are much higher than what can epidemiologically be considered safe. (74, 75) Limits set by a variety of national regulations are close to the current WHO guidelines. (38) However, it is important to understand that this limit was derived based on the assumption that a person will attend only X number of concerts a year; people attending loud amplified-music events more regularly will have a greater cumulative exposure and therefore greater risk of suffering hearing damage. Even when existing regulations are successfully applied measurements indicate that audience exposures can still be well above the WHO guidelines, for some areas within a venue. More clarity about measuring protocols (particularly location and correction) and the period of the continuous equivalent limit can aid in bringing exposure further down.

At-risk groups that need priority attention are:

1. Musicians: on-stage levels at pop/rock concerts are often very high, In-Ear monitoring can reduce this but needs professional guidance and regular exposure as

well as audiometric check-ups. Reducing exposure in smaller indoor venues particularly should start with a reduction in on-stage levels.

2. Live Sound Engineers (LSE), like musicians often fall outside of workplace safety regulations as a consequence of the murky status of free-lancers. Regular audiology check-ups should support LSE to become more aware of their own risks as well as the role they play in managing the exposure of other stakeholders.
3. Audience members immediately in front of the stage, particularly at large concerts with ground-stacked sub-woofer arrays can be exposed to peaks greater than 140dBC. Alternatives should be considered (56) and peak limiters should be in use to avoid any peaks greater than regulated peak levels measured at the nearest possible audience-ear (4)

Each of these three groups will benefit from greater awareness (targeting audiences), training (targeting musicians) and education and certification (targeting LSE). With respect to this last point the AES Working group on sound exposure and noise pollution due to outdoor entertainment events, proposes the Healthy Ears, Limited Annoyance (HELA) initiative in its recent report Understanding and managing sound exposure and noise pollution at outdoor events. (1) Venues, Sound Engineers or even bands could sign up to such an initiative to indicate their ability and willingness to work with the best SLMMMM practices for both hearing damage risk mitigation as well as environmental noise reduction. The proposed abbreviation HELA can be interpreted as the (Californian) slang for very. As a result, stakeholders have the chance to become HELA-compliant.

The challenges are worse in small indoor venues, and prioritising is warranted:

4. Cumulative patron numbers in small venues can be surprisingly high, particularly in the major cities (64). Exposure can be very high across a venue as a combination of room size and on-stage sound levels.
5. With appropriate sound proofing environmental regulations that ordinarily dictate maximum sound levels within venues play no part in SLMMM aimed at reducing audience exposure. Funding or grants that support venues' sustainability through sound proofing should include SLMMM strategies targeting audience exposure.
6. Traditionally the SPL A-weighting has been in use as an indicator of hearing damage risks and the SPL C- weighting to predict and control emission into the environment (even though often assessed inside neighbouring premises using A-weighting). This means that both weightings need to be monitored (at FOH) in order to comply.

Sound (pressure) Level Measurement, Monitoring, and Management (SLMMM) and documentation strategies can help realising levels that are enforced locally. Measurements taken at FOH or in the audience are displayed to the FOH operators as continuous equivalent levels over periods and weighted according to local provisions. The choice of values as well as the type of display (e.g. traffic light, dosage remaining, in time or dB) can influence the mixing decisions depending on the level if experience of the operator and whether limits are voluntary or (strictly) enforceable.

A few issues with this process stand out and require further research.

1. Sound levels on-stage can be very high and this is not always reflected in current measurement protocols.
2. Differences between in and outdoor venues, as well as indoor venue size, influence the outcomes of measurements. New and existing measurement protocols need to be verified for consistency across a range of venues, alternatively different protocols will need to be specified for outlier venue (e.g. outdoor festival and small urban venue)
3. Short L_{eq} integration periods (3-15 minutes) help venues and their operators implementing limits, as well as enforcement official to make reliable measurements. Longer periods (e.g. 60 minutes) are more appropriate to keep track of how an event is progressing towards the allowable dosage, while allowing for dynamic range. Research is needed to find evidence for the most effective integration period, or combination of periods (e.g. the Flemish regulation which is includes both a 60-minute and a 15-minute integration period).

8 References

1. Hill AJ. Managing sound exposure and noise pollution at outdoor events. AES Technical Committee on Acoustics and Sound Reinforcement; 2020.

2. Beach E, Cowan R, Mulder J, O'Brien I. Applying the hierarchy of hazard control to regulation of sound levels in entertainment venues. Annals of Work Exposures and Health. 2020;64(4):342-9.

3. M E. Gehörschutz auf Veranstaltungen: 10 Jahre DIN 15905-5 2017 [Available from: https://www.production-partner.de/story/10-jahre-din-15905-5/.

4. Ebner M, Knoll J. Gehörgefährdung des Publikums bei Veranstaltungen: Kommentar zu DIN 15905-5: Beuth Verlag; 2009.

5. Pisfil S. Loud rock music? Live sound in the late 1960s. In: Schopf FJ, editor. Music on Stage Volume III. London: Cambridge Scholars Publishing; 2018.

6. Pisfil S. Towards a New History of Rock Music: Documenting Live Sound between 1967 and 1973. Edinburgh: University of Edingburgh; 2018.

7. Pisfil S. Woodstock and the Live Sound Industry in the Late 1960s. Popular Music and Society. 2019:1-12.

8. Kane J. The Last Seat in the House: The Story of Hanley Sound. Jackson: University Press of Mississippi; 2020.

9. Reeder NC. The Co-Evolution of Improvised Rock and Live Sound: The Grateful Dead, Phish, and Jambands. Providence: Brown University; 2014.

10. Yahata Y, Suzuki Y, editors. Actual sound pressure levels at pop-music concerts Historical review from the 1920s to the present. Internoise 2003: The 32nd International Congress and Exposition on Noise Control Engineering; 2003; Seogwipo, Korea.

11. Welch D, Fremaux G. Understanding why people enjoy loud sound. Seminars in hearing. 2017;38(04):348-58.

12. Welch D, Fremaux G. Why do people like loud sound? A qualitative study. International journal of environmental research and public health. 2017;14(8):908.

13. Brown SC, Knox D. Why go to pop concerts? The motivations behind live music attendance. Musicae Scientiae. 2017;21(3):233-49.

14. Kronenburg R. Live Architecture: Venues, Stages and Arenas for Popular Music. London; New York: Taylor & Francis; 2012.

15. Bagenal H, Wood A. Planning for good acoustics: Methuen; 1931.

16. Forsyth M. Buildings for music: the architect, the musician, and the listener from the seventeenth century to the present day. Cambridge: Cambridge University Press; 1985.

17. Webster E. Live Music Exchange Blog [Internet]. UK2012. [cited 2020]. Available from: https://livemusicexchange.org/blog/live-music-101-4-venue-typologies-an-overview-emma-webster/.

18. Adelman-Larsen NW. Rock and Pop Venues: Acoustic and Architectural Design: Springer; 2014.

19. Bray A, Szymański M, Mills R. Noise induced hearing loss in dance music disc jockeys and an examination of sound levels in nightclubs. The Journal of Laryngology & Otology. 2004;118(2):123-8.

20. Arenas JP, Suter AH. Comparison of occupational noise legislation in the Americas: an overview and analysis. Noise and Health. 2014;16(72):306.

21. Wolniakowska A, Zaborowski K, Dudarewicz A, Pawlaczyk-Łuszczyńska M, Śliwińska-Kowalska M. Assessment of temporary hearing changes related to work as a bartender. 2019.

22. Barlow C, Castilla-Sanchez F. Occupational noise exposure and regulatory adherence in music venues in the United Kingdom. Noise and Health. 2012;14(57):86-90.

23. Ghent Jr RM. Workplace noise regulations in the music industry: a square peg and a round hole. Journal of the Audio Engineering Society. 2013;61(9):667-75.

24. Babin A. Orchestra pit sound level measurements in Broadway shows. Medical Problems of Performing Artists. 1999;14:204-9.

25. Chikezie CC, Alabere ID. Occupational Noise Exposure and Hearing Impairment among Employees of Nightclubs in Port Harcourt Metropolis. Asian Journal of Medicine and Health. 2018;13(4):1-11.

26. Perna M, Padois T, Dumoulin R, Doutres O, Dupont T. Noise from outdoor music activities: selected examples of regulations and recommendations.26th International Conference on Sound and Vribration; Montreal2019.

27. Parnell J, Sommer R, editors. Setting noise objectives for outdoor music festivals in rural locations. Proceedings of ACOUSTICS; 2018.

28. Parnell J, Hartcher A, editors. Setting noise objectives for outdoor events at the Sydney Opera House. Acoustics 2017; 2017; Perth.

29. Kok M, editor Sound Level Measurements & Control at Large Dance Events. Audio Engineering Society Conference: 58th International Conference: Music Induced Hearing Disorders; 2015; Aalborg.

30. Griffiths J. Environmental Noise Guidelines and Sound Management for UK Concerts. Proc CFA/DAGA, Strasbourg. 2004.

31. Marchuk A, Henry F, editors. Regulatory Strategies for Managing Noise from Outdoor Music Concerts. Proceedings of ACOUSTICS 2016; 2016; Brisbane.

32. Music_Venue_Trust. Understanding Small Music Venues. Music Venue Trust; 2015.

33. Johnson B, Homan S. Vanishing acts: an inquiry into the state of live popular music opportunities in New South Wales| NOVA. The University of Newcastle's Digital Repository. 2003.

34. Gibson C, Homan S. Urban redevelopment, live music and public space: Cultural performance and the re-making of Marrickville. International journal of cultural policy. 2004;10(1):67-84.

35. Lee G, editor Agents of change in Melbourne's live music scene: A practical review. INTER-NOISE and NOISE-CON congress and conference proceedings; 2016: Institute of Noise Control Engineering.

36. Henry FD, Mackenzie KC. Managing Noise Impacts In Brisbane's Fortitude Valley Entertainment Precinct.Acoustics 2004; Gold Coast2004.

37. Burke M, Schmidt A. How should we plan and regulate live music in Australian cities? Learnings from Brisbane. Australian Planner. 2013;50(1):68-78.

38. Berglund B, Lindvall T, Schwela D. Guidelines for community noise. Geneva: World Health Organization; Cluster of Sustainable Development and Healthy Environment (SDE) Department of the Protection of the Human Environment (PHE) Occupational and Environmental Health (OEH); 1999.

39. Lechner C, editor Control of music noise with sound level limiters. Proceedings of the International Congress and Exhibition on Noise Control Engineering; 2001.

40. Wendl M, Lee H, editors. The effect of dynamic range compression on loudness and quality perception in relation to crest factor. Audio Engineering Society Convention 136; 2014: Audio Engineering Society.

41. Moore BC, Glasberg BR, Stone MA. Why Are Commercials so Loud?'Perception and Modeling of the Loudness of Amplitude-Compressed Speech. Journal of the Audio Engineering Society. 2003;51(12):1123-32.

42. Durbridge SE, Hill AJ, Taylor J, editors. The effects of distortion on the perception of loudness in live sound. Proceedings of the Institute of Acoustics; 2015.

43. Makarewicz G, Lewandowski M, editors. Sound Level Control Based on Grey System Theory for Protection Against Hearing Damage Risk in Music Entertainment Venues. 2018 Joint Conference - Acoustics; 2018 11-14 Sept. 2018.

44. McIlvaine D, Stewart M, Anderson R. Noise exposure levels for musicians during rehearsal and performance times. Medical problems of performing artists. 2012;27(1):31.

45. McCarthy B. Sound systems : design and optimization : modern techniques and tools for sound system design and alignment / Bob McCarthy. 1st ed. ed. Oxford ; Burlington, MA :: Focal; 2007.

46. Sandell J, Berntson A, Sjösten P, Blomgren G, Kähäri K. Acoustic intervention in a live music club. Acta Acustica United With Acustica. 2007;93(5):843-9.

47. Clarke J, editor Source Separation in Action: Demixing the Beatles at the Hollywood Bowl. Audio Engineering Society Convention 142; 2017: Audio Engineering Society.

48. Santucci M. Personal in the ear monitoring. In: Chasin M, editor. Hearing loss in musicians [electronic resource] : prevention & management. San Diego: Plural; 2008. p. 101-9.

49. Nykänen A, Löfdahl M, Johannesson T, Berg J, editors. Do In-Ear Monitors Protect Musicians' Hearing? Audio Engineering Society Convention 142; 2017: Audio Engineering Society.

50. Federman J, Ricketts T. Preferred and minimum acceptable listening levels for musicians while using floor and in-ear monitors. Journal of Speech, Language, and Hearing Research. 2008;51(1):147-`59.

51. Berg J, Johannesson T, Löfdahl M, Nykänen A, editors. In-ear vs. loudspeaker monitoring for live sound and the effect on audio quality attributes and musical performance. Audio Engineering Society Convention 142; 2017: Audio Engineering Society.

52. Kelly AC, Boyd SM, Henehan GTM, Chambers G. Occupational noise exposure of nightclub bar employees in Ireland. Noise & health. 2012;14(59):148-54.

53. McGinnity S, Mulder J, Beach EF, Cowan R, editors. Investigating the Use of Sound Level Management Software in Live Indoor Music Venues. Audio Engineering Society Conference: 2018 AES International Conference on Music Induced Hearing Disorders; 2018; Chicago: Audio Engineering Society.

54. 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.

55. Navne J, editor Sound Level Measurements Made Eazy: 10Eazy–Intuitive SPL Monitoring for Live Sound Events. Audio Engineering Society Conference: 58th International Conference: Music Induced Hearing Disorders; 2015; Aalborg.

56. 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. Reproduced Sound; 2019; Bristol: Institute of Acoustics.

57. Becerra Benítez CE, editor Loudness Metering in Sound Reinforcement: Utilities and Practical Considerations. Audio Engineering Society Convention 145; 2018: Audio Engineering Society.

58. Støfringsdal B, editor Expected Sound Levels at Concert Venues for Amplified Music. Auditorium Acoustics 2018; 2018; Hamburg.

59. Debruyne S. Eindrapport Evaluatie Regelgeving Muziekactiviteiten volgens Bestek nr. LNE/LHRMG/OL201300003. Brussels: Bureau de Fonseca; 2015.

60. Tronstad T, Gelderblom F. Sound exposure during outdoor music festivals. Noise and Health. 2016;18(83):220-8.

61. Guo J, Gunn P. Entertainment noise in western australia. Proceedings of Acoustics 2005. 2005:211-5.

62. Tittman SM, Yawn RJ, Manzoor N, Dedmon MM, Haynes DS, Rivas A. No Shortage of Decibels in Music City: Evaluation of Noise Exposure in Urban Music Venues. The Laryngoscope.n/a(n/a).

63. Roberts B, Kardous C, Neitzel R. Improving the accuracy of smart devices to measure noise exposure. Journal of Occupational and Environmental Hygiene. 2016;13(11):840-6.

64. Newton D, Coyle-Hayward R. Melbourne live music census 2017 report. Melbourne: Music Victoria; 2018.

65. Ryberg J. A national project to evaluate and reduce high sound pressure levels from music. Noise and Health. 2009;11(43):124-8.

66. Pierre Jr R, Maguire DJ, editors. The impact of A-weighting sound pressure level measurements during the evaluation of noise exposure. Conference NOISE-CON; 2004.

67. Mercier V, Luy D, Hohmann B. The sound exposure of the audience at a music festival. Noise and Health. 2003;5(19):51.

68. Cazals Y, Campo P, Job A, Madec L, Puel J-L, Ramogolan K, et al. Expositions aux niveaux sonores élevés de la musique: recommandations sur les niveaux acceptables. Haut Conseil de la santé publique; 2013.Contract No.: hal-01827855.

69. Ward W, Fletcher JH, Green DM, Hamernik RP, Johnson D. Hazardous exposure to impulse noise. NATIONAL RESEARCH COUNCIL WASHINGTON DC COMMITTEE ON HEARING BIOACOUSTICS …; 1992.

70. Borg C, editor An investigation of the sound pressure level at the Roskilde Festival. AES: 58th International Conference: Music Induced Hearing Disorders; 2015; Aalborg: Audio Engineering Society.

71. Jensen SB, Drastrup M, Morales EC, Pizarro REO, Borg C, editors. Sound exposure measurements using hearing-aid technology. 22nd International Congress on Acoustics; 2016: Asociación de Acústicos Argentinos.

72. Tronstad TV, editor Hearing Measurements During Two Norwegian Music Festivals. AES 58th International Conference: Music Induced Hearing Disorders; 2015; Aalborg: Audio Engineering Society.

73. Jamieson A, editor Use of and Attitudes Towards Hearing Protection in the Sound and Music Industries. Audio Engineering Society Conference: 58th International Conference: Music Induced Hearing Disorders; 2015; Aalborg.

74. Neitzel RL, Fligor BJ. Risk of noise-induced hearing loss due to recreational sound: Review and recommendations. The Journal of the Acoustical Society of America. 2019;146(5):3911-21.

75. Roberts B, Neitzel RL. Noise exposure limit for children in recreational settings: Review of available evidence. The Journal of the Acoustical Society of America. 2019;146(5):3922-33.

Appendix A:

Sound Level Monitoring Measurement and Management software.

This appendix shows four different examples of current SLMMM software programs. This is not an exhaustive list.

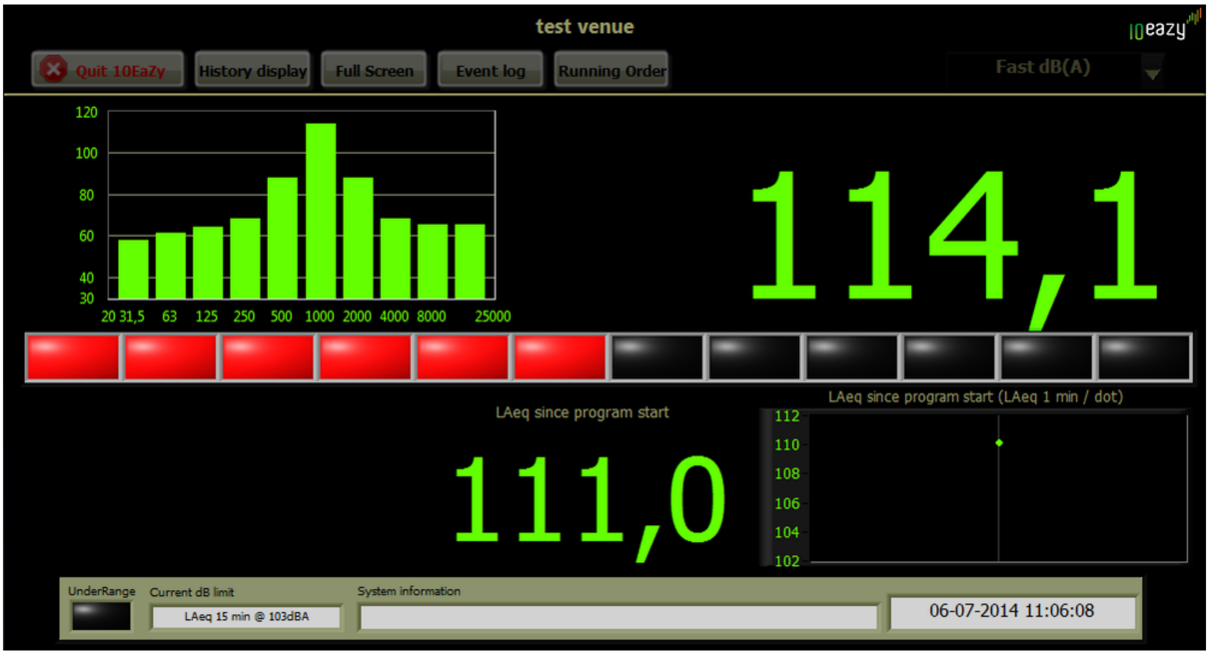

Fig.1 10EaZy (10eazy.com) The interface can display a variety of dB and L_{eq} values. The central bar with red and green segments ("traffic lights") indicates how much over or under the current L_{Aeq} value is with respect to a limit (in this case $L_{Aeq, `5min}$ =103dB). The metaphor in use to explain this approach is that of decibel banking; a concert begins with a certain amount of decibel credits in the bank and this tool helps an operator control the rate of spending, making sure the credits don't run out before the end of the concert. In 10eazy the traffic light system is called the Maximum Average Manager, which indicates that it was designed to realize as a concert at maximum level, without exceeding the limit.

10eazy is marketed with dedicated hardware interface (Class 1 or 2) that is calibrated to the measurement microphone that is sold with it.

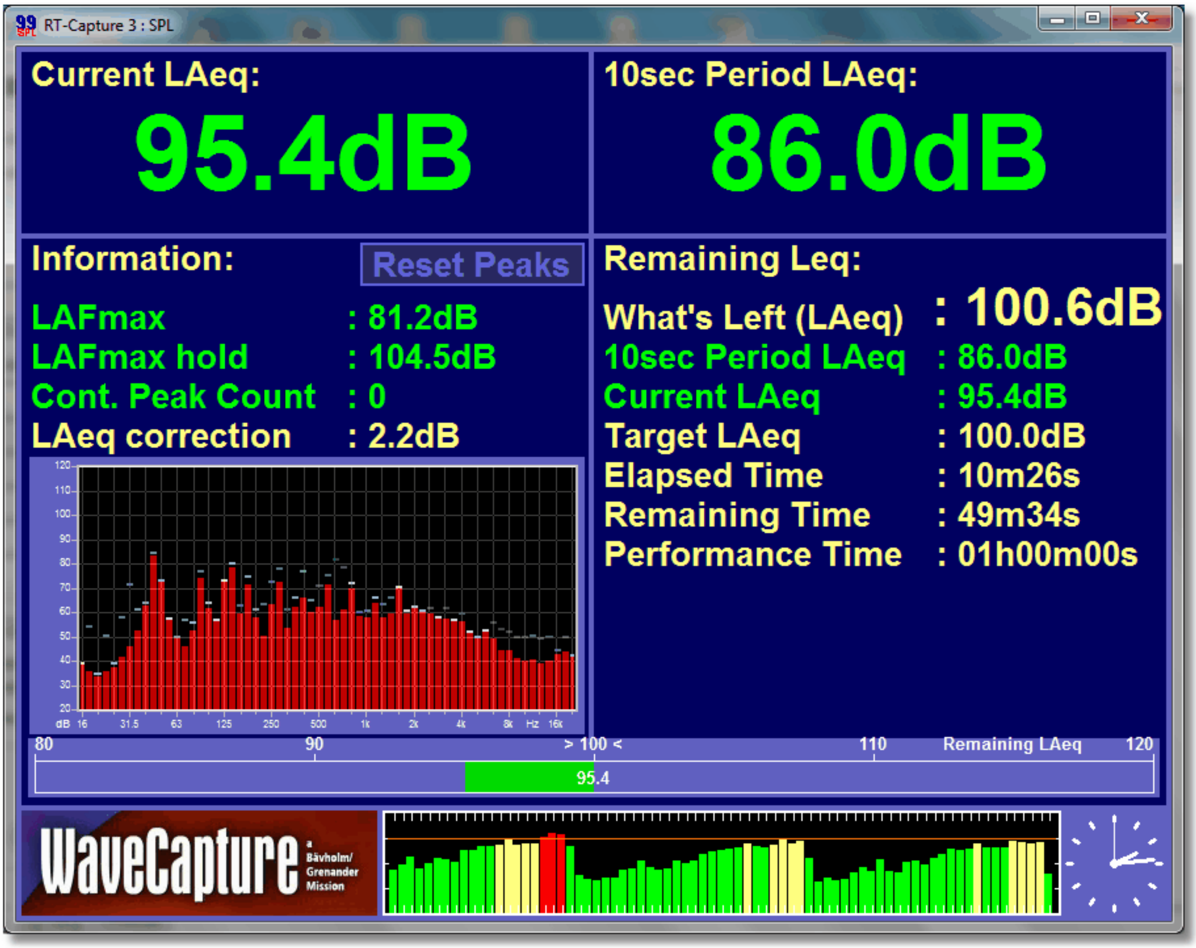

Fig 2. WaveCapture RT-3 (wavecapture.com). This is the operator display of a complete SPL logging and monitoring tool. Rather than a traffic light this display has a time remaining indicator as a way of indicating how much dB is left "What's Left (LAeq). The software is sold without hardware, a separate measurement microphone, audio interface and calibrator are required.

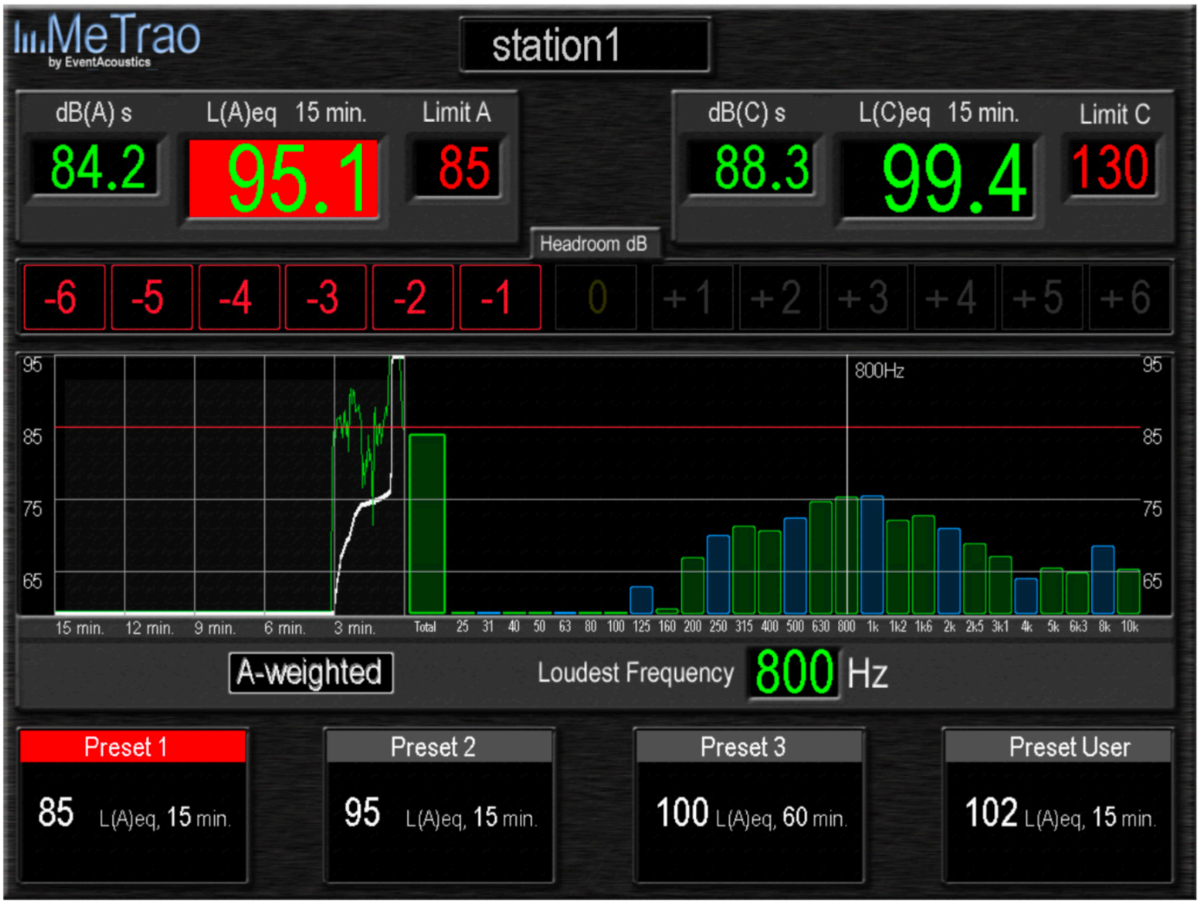

Fig. 3 Metrao. (metrao.com) This is the screen that comes with a complete set of hardware (class 1 or 2) that is designed to work in an ecosystem of many different measurement location. For instance, at a multi stage festival that also includes off-site monitoring of environmental noise impact.

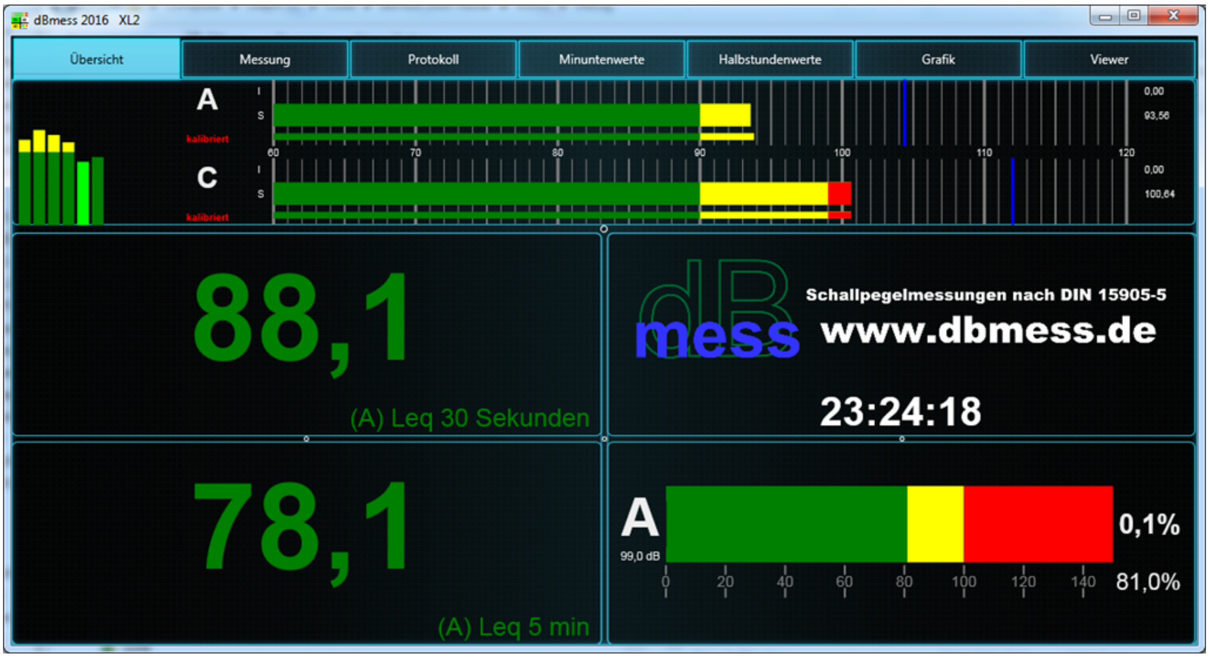

Fig 4. dbMess 2016 (dbmess.com) this is a software tool designed specifically for the German DIN norm and consequentially the German market. It works rather different in comparison with the other tools listed here, as the German norm uses averages per 30 minutes instead of a sliding average that is recalculated at every interval. The software is designed to work with a specific handheld SLM unit, the NTI-XL2.

Appendix B:

Literature Review of recent articles on Entertainment Sound Level Management

This report is in part informed by a systematic literature review into the topic of SLMMM in entertainment, specifically venues that present electronically amplified live music in the period 2016-2019. The aim of the review was to ascertain that all studies related to the topic are covered. Keyword combinations in English (e.g. ‘sound level management’ and ‘music’) were used to explore the databases of Pubmed, The Audio Engineering Society, IEEE Xplore, Inter-Noise conference proceedings.

Abbreviations: Temporary threshold shift (TTS), sound pressure levels (SPL), sound level management (SLM), sound engineer (SE), Distortion Product Otoacoustic Emissions (DPOAEs), front-of-house (FOH).

Year	Reference	Objective	Sample	Method	Results	Conclusions
2020	Beach, Elizabeth, Robert Cowan, Johannes Mulder, and Ian O'Brien. 2020. "Applying the hierarchy of hazard control to regulation of sound levels in entertainment venues."*Annals of Work Exposures and Health* 64 (4):342-349. doi.org/10.1093/annweh/wxaa018.	Commentary		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.		
2020	Hill, Adam J. 2020. Managing sound exposure and noise pollution at outdoor events. In *Working group on sound exposure and noise pollution due to outdoor entertainment events*: AES	Report				

	Technical Committee on Acoustics and Sound Reinforcement.					
2019	Wolniakowska, A., Zaborowski, K., Dudarewicz, A., Pawlaczyk-Łuszczyńska, M., & Śliwińska-Kowalska, M. (2019). Assessment of temporary hearing changes related to work as a bartender. *Medycyna Pracy*, *70*(1), 17–25. doi: 10.13075/mp.5893.00734	To assess the relationship between noise exposure and any temporary threshold shift (TTS) in bartenders of entertainment venues.	Entertainment venue bartenders (18) employed at a music club (8), pub (5) and discotheque (5).	A. Personal dosimetry of sound pressure level (SPLs) and frequency characteristics. B. Pure-tone audiometry pre- and post-exposure (Within 15-mins after a work-shift). Conducted during weekend shifts. TTS defined as ≥10dB HL change in threshold.	Mean noise exposure level of 95 dBA, normalized to nominal 8-hour working day. TTS was significant at 4 kHz for both ears for 77% of participants.	Bartenders in entertainment venues face an increased risk of hearing loss.
2020	McGinnity, Siobhan, Johannes Mulder, Elizabeth Francis Beach, and Robert Cowan. 2019. "Management of Sound Levels in Live Music Venues."*Journal of the Audio Engineering Society* 67 (12):972-985.	To investigate if implementation of and access to a SLM system will lead to a reduction in sound level exposure of patrons and staff of an indoor live music venues.	Six small urban music venues in Melbourne	Intervention with sound level management software; pre and post analyses	Varying.	When used properly sound level management software can help reducing audience exposure.
2019	Wartinger, F., Malyuk, H., & Portnuff, C. D. F. (2019). Human exposures and their associated hearing loss profiles: Music industry professionals. *The Journal of the Acoustical Society of America*, *146*(5), 3906–3910. doi: 10.1121/1.5132541	REVIEW – excluded.				
2019	Beach, E. F., & Gilliver, M. (2019). Time to Listen: Most Regular Patrons of Music Venues Prefer Lower Volumes. *Frontiers in Psychology*, *10*, 1–16. doi: 10.3389/fpsyg.2019.00607	To explore if sound levels in music venues reflect the preferences of patrons.	Regular patrons of nightclubs and live music venues (n = 993).	Australian online hearing health survey querying the following; participation at two target venues, experience of hearing difficulties, risk perceptions, preferences	Participants rated their hearing as good, yet the majority had experienced hearing difficulties following sound exposure at music venues.	Emphasis on encouraging entertainment venues to meet the sound level preferences of patrons, rather than motivating behavior change in patrons.

				in relation to typical venue sound levels and beliefs about other attendees' preferences.	Three-quarters of participants reported sound level preferences for below those typically experienced in venues. The majority believed that their hearing was at risk, 40% to a high level. Those who regarded themselves to be at greater risk from attending music venues were more likely to prefer lower sound levels.	
2019	Reybrouck, M., Podlipniak, P., & Welch, D. (2019). Music and Noise: Same or Different? What Our Body Tells Us. *Frontiers in Psychology*, *10*(JUN). doi: 10.3389/fpsyg.2019.01153	Review - excluded				
2019	Hill AJ, Kok M, Mulder J, Burton J, Kociper A, Berrios A. A case study on sound level monitoring and management at large-scale music festivals. Proceedings of the Institute of Acoustics Conference on Reproduced Sound; 2019 Nov 20; Bristol: Milton Keynes: Institute of Acoustics. 41(3):1-16.	To investigate whether trends found in an indoor music venue study[27] agree with what occurs at large-scale outdoor music festivals.	Sound levels of two main stages (Green and Red) at Pitchfork Music Festival, Chicago, with a "live" time (music playing) of roughly 8hrs/day.	Design of each stage's sound system as close to identical as possible in set-up. Sound level monitor (SLM) in use at both. Sound limits for support acts (96dB $L_{Aeq,\ 5min}$; 106dB $L_{Ceq,\ 5min}$) and headliners (100 dB $L_{Aeq,\ 5min}$; 110 dB $L_{Ceq,\ 5min}$) set. At all times,	Sound levels: At the red stage, over limits for 23-mins (3% of live time) during the festival, and 4-hrs and 2-mins (38% of live time) at the green stage. Engineers who could see the SLM mixed on average 2 dBA quieter. Average mix level without	The use of noise monitoring software with an A-weighted limit is unlikely to do anything significant to stem annoyance in the local community. Audience exposed to significant, potentially dangerous SPL. Standard foam earplugs inefficient against levels experienced. Use of A-weighted limits will not capture this issue. Recommendation for ground-based subwoofer systems not to be used as precaution. Furthermore, use of SLM with an A-weighted limit unlikely to reduce local community noise annoyance.

27 McGinnity, S., Mulder, J., Beach, E. F., & Cowan, R. (2018). Investigating the use of sound level management software in live indoor music venues. In D. Hammershøi & J. Boley (Eds.), *Music-Induced Hearing Disorders* (pp. 1–10). Chicago, USA: Audio Engineering Society.

				the monitoring software was out of sight of engineers at the Green stage. Sound engineers (SE) at the Red stage, however, could see the dBA levels only from the monitoring system. Audience worst-case scenario location inspected (front most rows, as close as 2m from speaker arrays).	view (3.83 dBA) and with (1.51 dB) below limit. Dynamic range: No significant reduction in C-weighted range, however A-weighted dynamic range reduced by more than 3dB at the Red (monitored) stage. Crowd size, SE type and time slot were significant factors in Absolute FOH sound level. Average FOH SPL differed for low (92.5 dBA), medium (95 dBA) and large (96.1 dBA) crowd sizes ($L_{Aeq,\ 5min}$). Average FOH SPL differed by type of engineer (House = 92.7 dBA; Band = 95.6 dBA). Audience closest to stage exposed to low-frequency SPL consistently between 120-130 dBC peak ($L_{Ceq,\ 5\text{-}min}$), peaking around 140 dBC daily.	Use of the SLM lead to reduced time over the limits. However, engineers who could see the SLM compressed (reduced dynamic range) their mix to comply with them. Band engineers tended to mix significantly louder than house technicians.
2019	Roberts, B., & Neitzel, R. L. (2019). Noise exposure limit for children in recreational settings: Review of available evidence. *The Journal of the Acoustical Society of America*, *146*(5), 3922–3933. doi:10.1121/1.5132540	[Review] To establish acceptable risk	A recreational noise limit defined by protecting 99% of children from hearing loss (>5dB at 4kHz) after 18yrs of	ISO 1999:2013 model used to predict hearing loss.	Estimated that noise exposure equivalent to an 8-h average exposure (LEX) of 82 dBA would result in < 4.2 dB of hearing loss in 99% of	

		of hearing loss in children.	exposure was defined.		children after 18 years of exposure. The 8-h LEX was reduced to 80 dB to include a 2 dB margin of safety. This 8-h LEX of 80 dBA is estimated to result in 2.1 dB or less of hearing loss in 99% of children after 18 years of exposure. This is equivalent to 75 dBA as a 24-h equivalent continuous average sound level.	
2019	Chikezie, C. C., & Alabere, I. D. (2019). Occupational Noise Exposure and Hearing Impairment among Employees of Nightclubs in Port Harcourt Metropolis. *Asian Journal of Medicine and Health*, *13*(4), 1–11. doi:10.9734/AJMAH/2018/45955	"To determine the level of occupational noise exposure and hearing impairment among employees of night clubs in Port Harcourt metropolis."	Night club employees (n = 260).	A. Semi-structure interviewer administered questionnaire. B. Hearing test. C. SPL measurement.	Average SPL in the nightclubs of 100.9 dBA. Employees: 93.7% worked ≥8-hrs daily. 98.8% did not use hearing protection. Most common reason (69.9%) for non-use was managements' failure to provide. 71.1% had a mild hearing loss. Hearing loss was associated with age, sex, educational status previous occupational noise exposure, employment duration, and job description.	Night club employees are exposed to SPL above the maximum permissible limit of 85 dB, 8-hrs daily.
2019	Roberts, B., Seixas, N. S., Mukherjee, B., & Neitzel, R. L. (2018). Evaluating the Risk of Noise-Induced Hearing Loss Using Different Noise Measurement	Excluded				

	Criteria. *Annals of Work Exposures and Health*, *62*(3), 295–306. doi: 10.1093/annweh/wxy001					
2018	Dudarewicz, A., Zaborowski, K., Wolniakowska, A., Pawlaczyk-Łuszczyńska, M., & Śliwińska-Kowalska, M. (2018). Evaluation of on-the-job noise exposure in the case of bartenders. *Medycyna Pracy*, *69*(6), 633–641. doi: 10.13075/mp.5893.00735	To assess on-the-job noise exposure of bartenders in three entertainment venues.	Three entertainment venues in Łódź: a music club (1), disco (1) and pub (1).	"Individual" dosimetry of bartenders at 4 workstations.	Sound levels: Range between 67.6-108.7 dBA. Varied greatly depending on type of premises and day of week. Highest SPL measured on weekends (Friday, Saturday). Employees: Daily noise exposure levels exceeded 80 dB (preventative action threshold) in 95% of cases. Maximum permissible noise level (NDN of 85 dB) was exceeded in 66% of cases.	On-the-job noise levels of bartenders significantly exceed the acceptable values of exposure levels and pose a risk of hearing damage.
2018	Beach, E. F., Mulder, J., & O'Brien, I. (2018). Development of guidelines for protecting the hearing of patrons at music venues: Practicalities, pitfalls, and making progress. In D. Hammershøi & J. Boley (Eds.), *International Conference on Music-Induced Hearing Disorders* (pp. 1–5). doi: 10.17743/aesconf.2018.978-1-942220-20-6	Review - excluded				
2018	Szibor, A., Hyvärinen, P., Lehtimäki, J., Pirvola, U., Ylikoski, M., Mäkitie, A., … Ylikoski, J. (2018). Hearing disorder from music; a neglected dysfunction. *Acta Oto-Laryngologica*, *138*(1), 21–24. doi: 10.1080/00016489.2017.1367100		Clinic patients with music-induced hearing disorder (n = 104).	Hearing: Pure-tone audiometry (.125-12kHz), tinnitus pitch and loudness matching. Questionnaires: Tinnitus Handicap Inventory (THI; 0-100), visual analog scales (VAS; 0-100%) for tinnitus loudness,	For participants, traumatic exposure to SPL had occurred in concerts (41%), nightclubs (31%), during bands playing (21%), using headphones (4%) or studio work (2%). 1% could not identify the incident. Tinnitus was the presenting symptom in all cases, heard most often as a high-frequency tone	"Music-induced acute acoustic trauma is not inevitably linked to hearing dysfunction as validated by conventional pure tone audiometry. Tinnitus is often in combination with hyperacusis. Our results point at 'silent hearing loss' as the underlying pathology, having afferent nerve terminal damage rather than hair cell loss as the structural correlate."

				annoyance and awareness.	(78%). Many reported hyperacusis (65%), sleeping disorders (71%), concentration disorders (40%) and anxiety (40%). Hearing was normal in 60% of patients, 31% had "chronic" high-frequency hearing loss, 9% mild low frequency hearing loss. THI responses averaged 43.1 (range 0 to 94). VAS indicated average loudness was 42.4, annoyance of 54.2, and awareness of 60.3. All VAS strongly correlated to THI results.	
2018	McGinnity, S., Mulder, J., Beach, E. F., & Cowan, R. (2018). Investigating the use of sound level management software in live indoor music venues. In D. Hammershøi & J. Boley (Eds.), *Music-Induced Hearing Disorders* (pp. 1–10).	To investigate if implementation of and access to a SLM system will lead to a reduction in sound level exposure of patrons and staff of an indoor live music venues.	Preliminary results of a larger study, reporting on results from 1 of 6 indoor live music venues. Surveys of 61 patrons and 6 venue staff.	Sound levels: Dosimetry at fixed locations throughout the venue (once per treatment condition), and daily monitoring of SPLs via the SLM system for each concert. Intervention: During the first month (Phase A) the SLM recorded L_{Aeq} values (1, 15 and 60-mins), as well as dBC recordings. The SLM was not visible to the SE. During the second month (Phase B), a nominal L_{Aeq} limit was selected by the venue,	Symptoms of hearing injury post music exposure were high for patrons, with tinnitus (57.4%) most common. Use of hearing protection was rare, with 75.4% having never worn them. Sound levels: Mean L_{Aeq} of 93 dBA, and 94 dBA in Phase B. Significant main effect of engineer and intervention found on sound levels, with guest engineers tending to mix at higher SPL than in-house technicians, and SPLs lower in pre-intervention. However,	No overall reduction in sound level exposure observed using the SLM system, yes use may lead to less time spent at higher SPLs. The traffic light system may also lead to SE's "aiming" for the target, as opposed to staying below it.

				and the SLM software was placed in sight of the SE. Surveys: Taken once during both treatment conditions with staff and patrons.	significantly less time spent at high SPLs (above 98 dB $L_{Aeq,\ 1min}$) with the SLM system in use.	
2018	Støfringsdal, Bård. 2018. "Expected Sound Levels at Concert Venues for Amplified Music." Auditorium Acoustics 2018, Hamburg.	Progress report on continuous sound level monitoring project in music venues across Norway.				
2017	Pouryaghoub, G., Mehrdad, R., & Pourhosein, S. (2017). Noise-Induced hearing loss among professional musicians. *Journal of Occupational Health*, *59*(1), 33–37. doi:10.1539/joh.16-0217-OA	To investigate the hearing health and use of protective measures among Iranian musicians.	Musicians (n=125), with ≥5yrs work experience.	Clinical and audiometric examination. Demographic data on hearing difficulties and hearing protection use collected via interviews.	Audiometry: audiometric notch present in either one or both ears for 42.4%, and bilateral hearing loss for 19.2%. History of tinnitus post performance (n = 64, 51%) and ear pain during performance (n = 35, 28%) common. Less than 2% of participants used hearing protection.	Musicians at risk of hearing loss due to high SPL exposure, yet use of hearing protection low due to inadequate knowledge of risk.
2017	Brown, S. C., & Knox, D. (2017). Why go to pop concerts? The motivations behind live music attendance. *Musicae Scientiae*, *21*(3), 233–249. Doi: 10.1177/1029864916650719	To explore the motivations of music fans deciding whether to attend live music concerts.	Participants (n = 249; 55% female)	Open-ended questionnaire thematically analysed under four themes; Experience, engagement, novelty and practical.	Motivations: to "be there", be a part of something unique/special, and share the experience with likeminded others. The use of live music events as a means to demonstrate fan worship also found. Novel aspects of live music key motivators e.g. hearing	"live music offers fans something special that they are more than willing to pay for."

					new material, watching support bands. Price not a contributing factor when choosing to attend.	
2017	Lindenbaum, C. (2017). Recreational Music Exposure and Music-Induced Hearing Loss: A Systematic Literature Review.	Review – excluded.				
2017	Walker, E. D., Hart, J. E., Koutrakis, P., Cavallari, J. M., VoPham, T., Luna, M., & Laden, F. (2017). Spatial and temporal determinants of A-weighted and frequency specific sound levels—An elastic net approach. *Environmental Research*, *159*(September), 491–499. Doi:10.1016/j.envres.2017.08.034	Excluded				
2017	Gjestland, T., & Tronstad, T. V. (2017). The efficacy of sound regulations on the listening levels of pop concerts. *Journal of Occupational and Environmental Hygiene*, *14*(1), 17–22. Doi:10.1080/15459624.2016.1207779	"To validate the efficacy of recommendations[i] for limits regarding sound exposure levels at live pop concerts."	Sound level data of student festivals (n = 2) recorded over 18 yrs. Festival A under municipal SPL restrictions, festival B not.	Analysis of new and previously collected data, validating the efficacy of recommendations for limits regarding sound exposure levels at live pop concerts. WHO recommendations introduced in 2000: total exposure limit 100dB $L_{p,A,4h}$ and 110dB $L_{p,AF,max}$.	Sound levels: SPLs tend to increase towards the end of a concert by up to 5dB. If an intermission exists, SPL are typically 3-5dB higher post intermission. Three concerts at the festival within the SPL restricted area saw increases of 1.8, 1.1 and 1.7 dB every two years between 1997 and 2005. After which, the trendlines (2005-15) turn negative, with SPL decreasing by -.0, -.4 and -.85 every two years, respectively. Meaning sound levels increased steadily up until 2005, after which they reduced and eventually	"Mild restrictions limiting the listening level at a live concert to around 100 dBA (half hour equivalent level) seem to be acceptable both for artists and spectators. This level also coincides with WHO recommendations for safe exposure. Such limiting values should therefore be promoted."

					stabilized below the recommended guidelines. At the festival (Hove) where no restrictions apply, the old “the-louder-the-better” concept seems to prevail. Risk of hearing injury is high for audience participants.	
2016	Le Prell, C. G. (2016). Potential contributions of recreational noise to daily noise dose. *The Council for Accreditation in Occupational Hearing Conservation*, 28(1), 1-3.	Exculded-review				
2016	Tereping, A. R. (2016). Listener preference for concert sound levels: Do louder performances sound better? *Journal of the Audio Engineering Society*, *64*(3), 138–146. doi:10.17743/jaes.2016.0004	To investigate the preferred sound level of participants at the Nordea Concert Hall in Tallinn.	146 participants.	Seven, one-minute live music samples were presented to the participants from the stage, performed by students of the Tallinn Georg Otts Music School. Participants then rated each sample on loudness, spaciousness, fidelity, clarity, brightness and overall pleasantness.	Preferred sound levels obtained between 73 to 85 dB $L_{Aeq.}$ No significant correlation between overall loudness and pleasantness found. Audio fidelity most significant factor to influence pleasantness.	“The main recommendation of this paper is that the rein- forced sound level at concerts should be within the limits of those preferred by listeners. Exceeding these limits does not result in satisfaction in the audience but can, instead, cause damage to their hearing and lead to high frequency hearing loss.”
2016	Ramakers, G. G. J., Kraaijenga, V. J. C., Cattani, G., van Zanten, G. A., & Grolman, W. (2016). Effectiveness of Earplugs in Preventing Recreational Noise–Induced Hearing Loss. *JAMA Otolaryngology–Head & Neck Surgery*, *142*(6), 551. doi:10.1001/jamaoto.2016.0225	“To assess the effectiveness of earplugs in preventing temporary hearing loss immediately following music exposure”	Normal hearing participants (n = 51) of a 4.5-hr outdoor music festival in Amsterdam.	Random participant allocation into either a protected (use of hearing protection) or unprotected group. Outcome measure: changes in hearing (TTS: defined as an average increase of ≥10dB at 3 and 4 kHz in ≥1 ear),	During the festival, the time-averaged, equivalent A-weighted SPL was 100dBA. Hearing: Instance of TTS significantly different between protected (4/50 ears; 8%) and unprotected (22/52 ears; 42%) group.DPOAEs (2-8kHz)	“Earplug use is effective in preventing temporary hearing loss after loud music exposure”

				DPOAEs or reports of tinnitus post exposure. Two researchers wore dosimeters (DC-122) during the festival to measure SPLs.	reduced significantly more in the unprotected (mean decrease = 2.8 dB) than protected (mean decrease = 1.8 dB) group. Tinnitus post-exposure was reported by 12% (protected) and 40% (unprotected) of participants.	
2016	Carter, L., Black, D., Bundy, A., & Williams, W. (2016). An Estimation of the Whole-of-Life Noise Exposure of Adolescent and Young Adult Australians with Hearing Impairment. *Journal of the American Academy of Audiology*, *27*(9), 750–763. doi:10.3766/jaaa.15100	"to determine whether a relationship between leisure-noise exposure and hearing loss exists."	Participants with normal hearing (NH; n = 296) and impaired hearing impaired (HI; n =125), analysed in two age groups; adolescents (13-17yrs) and young adults (18-24yrs).	Survey. Differences between the leisure profiles and exposure estimates of the HI and NH groups determined. Whole-of-life noise exposure was estimated.	Adolescents: Leisure profiles similar NH and HI groups. Few exceeded the risk criterion for exposure. Young adults: significantly less participation of leisure activities for HI group (7/18 activities participated in). Significantly lower activity diversity and whole-of-life exposure. Participation by both groups in leisure activities with high SPL demonstrated (HI < NH). Median whole-of-life exposure for HI group significantly lower than that for the NH group (710 versus 1,615 Pa2 h [Pascal squared hours])."	"The number of young adults with estimated exposure above the chosen noise-risk criterion in the NH group is concerning."
2016	Tronstad, T., & Gelderblom, F. (2016). Sound exposure during outdoor music festivals. *Noise and Health*, *18*(83), 220. doi:10.4103/1463-1741.189245	To explore if it is effective to regulate sound exposure at festivals with guidelines, as well as the reliability of	Two Norwegian music festivals, one regulated (Øya) by SPL guidelines, the other not (Hove).	Personal dosimeters placed with four participants monitored SPL exposure. Sound level exposure experienced at each festival compared each other, as well as against	The average daily exposure at Hove was 93.4 ± 1.0 dBA (range: 87.3–99.4dBA) and 92.6 ± 0.7dBA (range: 85.5–95.9 dBA at Øya. Mean concert sound levels significantly higher at Hove (101.4dBA)	The paper strongly supports the hypothesis that sound level restrictions are effective, and that it is possible to use FOH measurements to predict participant sound level exposure.

		using FOH measurements as an indicator of participant exposure.		both Norwegian ($L_{p,A,30\ min} = 99\ dB$) and WHO SPL guidelines.	than Øya (95.8dBA). The Norwegian sound level guidelines were exceeded more often at Hove (72% of concerts) than the Øya (29%). Concert time (mins) spent over 100 dBA were greater at Hove (47.7%) than Øya (11.8%). Participants of the unregulated festival were exposed to statistically significant higher sound levels than participants of the regulated festival. Front-of-house measurements reliably predicted participant exposure.	

[i] "The WHO recommendation for a maximum dose corresponding to $L_{p,A,4\ h}$ 100 dB and no more than four concerts per year has been derived from the same data that is being used by most European authorities for assessment of occupational noise. This yearly dose is comparable with an exposure of 8 hr per day and 40 hr per week at 80 dBA, which is equal to the normal occupational health limit with a 5 dB safety margin. The recommended maximum level, $L_{p,AFmax}$ 110 dB, also corresponds to the "old" occupational health standard. This limit has been replaced by a maximum peak requirement, $L_{p,Cpeak}$ 130 dB, after such measurements could readily be done." (pg. 20, Gjestland & Tronstad, 2017).