A CASE STUDY ON THE IMPACT LIVE EVENT SOUND LEVEL REGULATIONS HAVE ON SOUND ENGINEERING PRACTICE

AJ Hill College of Science and Engineering, University of Derby, UK
J Burton College of Science and Engineering, University of Derby, UK

1 INTRODUCTION

Audience safety and wellbeing has recently entered the spotlight, largely due to the ongoing work of the World Health Organization (WHO), namely their Make Listening Safe initiative[1]. A central focus of this initiative is to develop an international regulatory framework for safe listening at live music events, planned for release in 2021 (a comprehensive review of existing audience sound level regulations and guidelines is presented in a recently published AES Technical Document[2] which has fed into the WHO work). In order for this regularity framework to be effective and widely-adopted, it not only has to specify appropriate noise dosage limits and core principles for sound system design that should be followed, but also has to ensure that the noise exposure monitoring is practical for the sound engineer mixing the show.

While very large events may have a dedicated professional on hand to monitor and manage sound levels on- and off-site, most events' sound level control will be generally left to the sound engineer. It is therefore imperative that the sound level monitoring procedure is accessible and understandable to sound engineers and allows them to manage sound levels effectively and efficiently while still delivering the best possible listening experience to the audience.

This research focuses, therefore, on analyzing previously captured sound level measurements from recent tour and festival dates of a popular international touring act, looking for any effects the local sound level regulations may have had on overall sound level and live dynamic range. As all data analyzed in this work was generated by the same sound engineer mixing the same international touring act on (largely) the same sound system, differences in recorded levels will be due to a limited set of variables, namely: sound level regulations, venue characteristics and other event-specific circumstances. The first two parameters will be objectively examined while the third parameter will be commented on, where necessary.

The paper starts in Section 2 with a brief background on sound level regulations across the globe and related research, with suggested further reading, followed by a description of the data analysis methods in Section 3. An in-depth presentation and analysis of the research findings is given in Section 4 and the paper is concluded in Section 5.

It is the hope of the authors that these findings, although only a small sample of the activities normally carried out across the live event industry, will contribute to the development of practical and effective sound level management protocols, acceptable for all key stakeholders at live events.

2 BACKGROUND

Sound level monitoring at live events has been the focus of various research projects[3-13]. These studies generally include on-site measurements throughout the course of an event at the mix location (front-of house, FOH) and in some cases also from audience members who have chosen to participate by wearing noise dosimeters. The bulk of these studies are concerned with temporary noise-induced hearing loss, but some look into the measurable effects of using sound level monitoring software at such events[3,4].

There are a number of related studies which focus on aspects of sound/noise level management and monitoring at large-scale live events[3,5,6,9], quantification of annoyance levels due to different noise sources[14-19], health risks associated with sound exposure typically encountered at live events and aspects specifically related to low-frequency sound exposure (including infrasound)[9-13,20-35]. This published research is important in terms of the complete set of challenges encountered at live events but will not be expanded upon in this paper. Further reading of the referenced material is recommended for those working/researching in this field.

Regarding sound level regulations across the world, there is significant variation. The only region with clearly specified audience sound exposure regulations is Western Europe[2]. Inspecting the sound pressure level (SPL) limits, as well as the specified measurement time window, across the existing Western European regulations shows little agreement. Most limits are set around 100 dBA, but the measurement time window ranges from one minute up to the event duration. Attending an event which is limited to 100 dBA over one minute will be extremely different to attending an event which is limited to 100 dBA measured over the entire duration of the event. The latter will be able to deliver significant SPL peaks, likely resulting in a perceptually louder and more dynamic event.

This difference in measurement time window also can significantly impact the job of the sound engineer. A short measurement time window (often less than 5 minutes) results in the sound engineer having to constantly adjust the playback level to comply with the limit in place. This will inevitably distract the sound engineer from focusing on the musical quality of the mix. A long measurement time window (often 30 minutes or greater) generally does not cause such issues but fails to deliver timely information regarding sound level limit violations, making compliance with local regulations difficult. It is worth mentioning that the primary consideration of the sound engineer is in producing a high-quality experience for the audience, who are ultimately the client at any event.

One issue here is the measurement using a simple moving average (SMA), giving equal weighting to all sound level samples over the measurement time window. Another issue is the question of the most appropriate measurement time window. While a 15-minute window is commonly used amongst sound engineers, there is no known published medical data relating sound exposure measured in this manner to hearing health. Most existing knowledge is based on a one-hour measurement window (all using A-weighting – there is no significant published medical research focusing on C-weighted sound exposure measurements and hearing health). Both issues are beyond the scope of this project (and are the subject of separate ongoing projects) but are highlighted here to raise awareness of the complexity of the situation.

3 METHODS

Data for this research was gathered over a four-year period at a combination of indoor arena/theatre and outdoor open-air festival events. The indoor events varied in capacity between 2,500 – 25,000 people, while the open-air shows varied between 6,000 – 78,000 people, and as such they provide a representative cross-section of venue sizes for international touring headline acts[36].

The measurements were made at the FOH mixing position using a 10EaZy Class 1 measurement system[37]. Measurements were typically made at 35 – 45 m (at indoor shows) and 45 – 60 m (at open air venues) from the sound system. In cases where measurements were made outside of these parameters, they have been noted.

The measurement system was operated by one of the authors (Burton) as a guidance tool when working as the sound engineer for the international touring act. The 10EaZy system was used at all events as a secondary measurement system to monitor SPL levels independently of any other measurement system that may have been used at the events, for the enforcement of noise exposure regulations. The measurement system was also utilized to provide the author with an indication of the SPL at the mix position for personal reference. The current SPL was always available but other features such as the predictive level meter was disabled by setting the target level beyond the level that would be achieved during the performance (105dBA). The meter logged LAeq and LCeq measurements at 1-minute intervals, allowing for straightforward conversion to greater measurement time windows during data analysis for this research.

During the events where the data was collected every attempt was made to conform to the sound level regulations in place. Venues with no regulations were mixed at a sound pressure level that was felt by the author to be appropriate for the audience and venue size (typically 100 dB LAeq,15min).

Where secondary factors have affected the data in any significant way this has been noted by the authors by way of explanation. It is felt that the data represents a robust reflection of the sound pressure level across a wide range of venues around the world. The sound reinforcement systems used were all appropriate for the size of venue where they were deployed and are not considered a limiting factor to this study in any way. The control system and sound sources, as well as the source material, were consistent across all events. This data represents a single act performing a musical set that was also consistent across the shows, both in length and content, providing an ideal dataset for analysis. The data collected captured a greater time frame than the performance period and trimmed to contain only the musical performance period within the dataset (including the encore period which was a consistent feature of the concerts and important for consideration in terms of both dynamic and peak SPL).

The data analysis was performed by importing all 10EaZy logfiles into Microsoft Excel, while adding supplementary information such as venue capacity, venue type (indoor/outdoor), FOH location, SPL limits (including measurement time windows) for A- and C-weighting and any special notes for each event. The data in Excel was imported into Matlab for further analysis. Leq,1min data allowed for scaling the measurement time window to any value equal to or above one minute.

For each set of data, LAeq and LCeq values were determined for the relevant measurement time window. Additionally, LAmax and LCpeak values were inspected to determine live dynamic range. Live dynamic range was estimated using a prototype data analysis technique aiming at maintaining the natural musical level fluctuations within and between songs and removing the slower level adjustments by the sound engineer. This was accomplished by applying a 2nd order Butterworth high-pass filter to the 1-minute time series data with a cutoff frequency corresponding to a time period of 1-minute (the data was interpolated to give a 1 Hz sample rate). This process removes the DC-offset (in this case to be taken as mean sound pressure level from the event) as well as any level adjustments by the sound engineer, thus preserving the musical dynamic range from the act, as reinforced through the sound system. After the high-pass filter was applied, the live dynamic range was calculated based on the difference between L10 and L90 (the SPL exceeded 10% and 90% of the event, respectively). This was examined for A- and C-weighted data.

The purpose of inspecting the live dynamic range alongside the absolute sound level data was to determine if certain level limits and/or integration times cause a change in live dynamic range of the performance, which may affect the listening experience of the audience.

The impact of the following factors were inspected: venue type (indoor vs. outdoor), event type (tour vs. festival), venue capacity, presence of LAeq limit, presence of LCeq limit, LAeq limit, LAeq time, LCeq limit, and LCeq time. The results are presented and analyzed in the following section.

4 RESULTS AND ANALYSIS

Data was collected and analyzed from 130 events over a 5-year period (all by the same international touring act with the same sound engineer mixing each show). Initial analysis was carried out by plotting the Leq data versus time (with the appropriate measurement time window applied, according to the level regulations in place at each venue) along with calculations for live dynamic range. 52 and 3 events out of 130 had LAeq and LCeq limits, respectively. For events with no limit in place, LAeq was monitored and logged using a 15-minute measurement time window. All measurements were made at the front-of-house mix position (FOH). An example event analysis is shown in Figure 4.1.

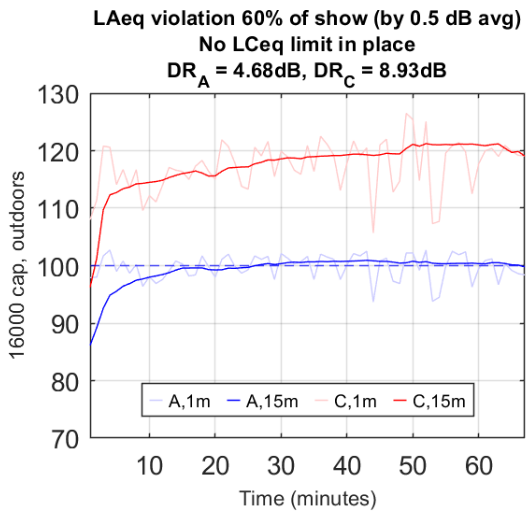

Figure 4.1 Example individual event data analysis (the vertical scale is in dB). The legend entries are in the format: weighting (A or C), measurement time window (minutes). DR_A and DR_C represent the live dynamic range with A- and C-weighting, respectively.

The individual event analysis provided a preliminary inspection of a level regulation's effects on sound level and live dynamic range. A more detailed, statistical analysis is required, however, to draw any clear and robust conclusions from the data. These analyses are presented in the following sections.

4.1 Venue characteristics

Before inspecting the influence of sound level regulations on the work of a live sound engineer, it is instructive to look at the impact the venue has on the overall sound level and live dynamic range of an event. Three characteristics were analyzed within this study: venue type (indoor or outdoor), event type (tour date or festival) and venue capacity.

While inspecting the data over the 130 analyzed events, all tour dates were indoors while all festivals were outdoors, aside from two outdoor tour dates and one indoor festival. For completeness, the analysis results for these two factors are shown side-by-side in Figure 4.2, where it can be observed that the data is nearly identical between the two graphs.

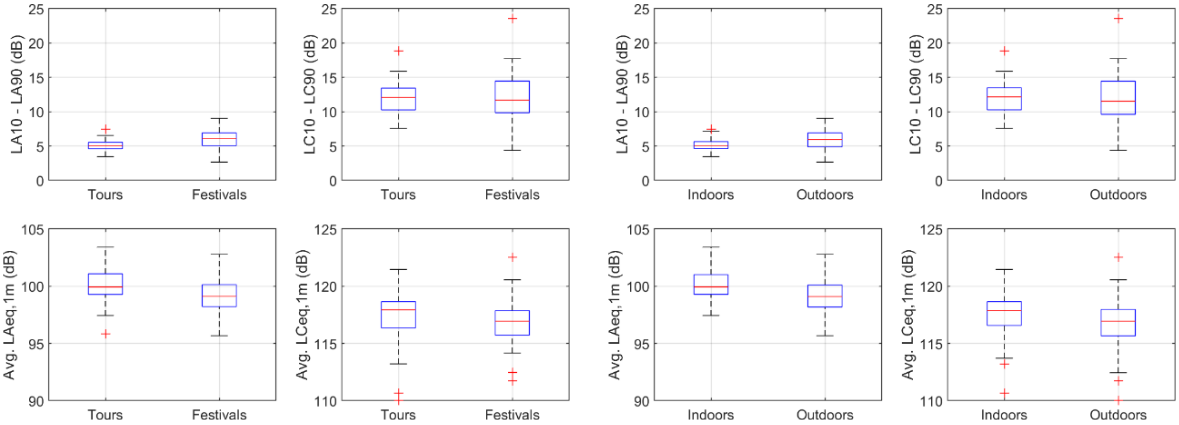

Figure 4.2 L10 – L90 (live dynamic range, in dB) and average Leq,1min (dB) inspected in relation to event type (tour or festival – 4 left plots) and venue type (indoors or outdoors – 4 right plots)

In respect to overall average sound level at events, there is a statistically significant difference for LAeq,1min ($p = 0.001$), with tours being generally around 1 dBA louder than festivals. The same

relationship holds true for indoor vs. outdoor venues (indoor events are roughly 1 dBA louder than outdoor events, $p = 0.002$). The LCeq,1min data shows a similar 1 dBC difference between tours and festivals as well as indoors and outdoors ($p = 0.050$ and $p = 0.001$, respectively).
A-weighted live dynamic range data showed a similar 1 dBA difference between tours and festivals as well as indoors and outdoors ($p = 3.99 \times 10^{-5}$ and $p = 1.46 \times 10^{-6}$, respectively), with the festivals and outdoors events exhibiting the greater live dynamic range. There was no significant relationship between venue/event type and C-weighted live dynamic range.

Venue capacity was also inspected in relation to the average sound level and live dynamic range at the events under analysis (Figure 4.3).

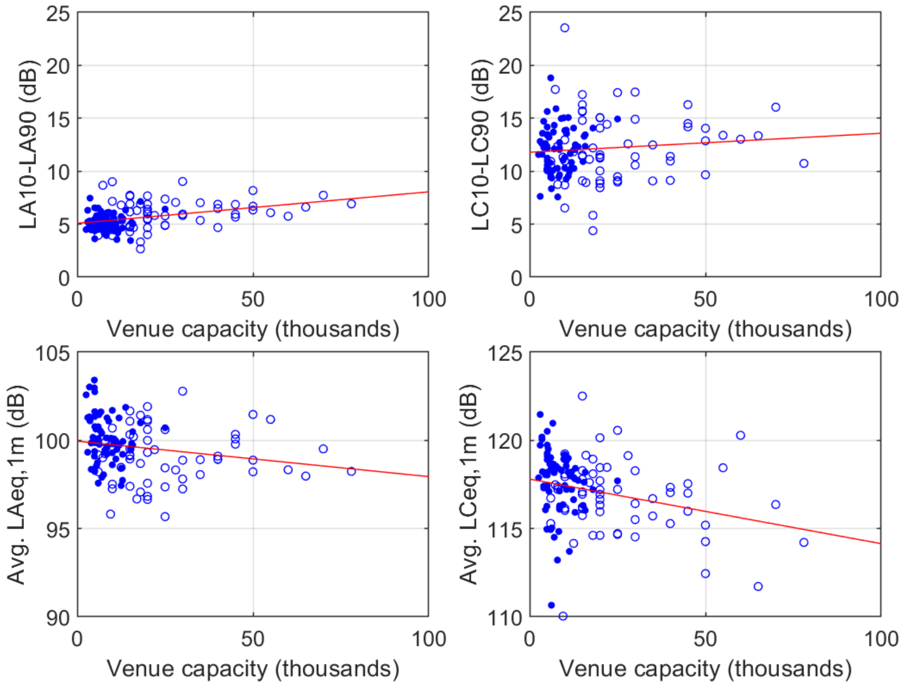

Figure 4.3 L10 – L90 (live dynamic range, in dB) and average Leq,1min (dB) inspected in relation to venue capacity (filled circles = indoor venues, empty circles = outdoor venues)

Live dynamic range (both A- and C-weighted) shows a slight upward trend with venue capacity. Several possible explanations exist for this. First, the acoustics of larger venues may be less problematic in terms of delivering the desired listening experience due to the sparsity and late arriving nature of reflections. Additionally, it is likely that the act's on-stage sound level (instrument amplification and personal monitoring system) will have less impact on the overall SPL at the FOH mix position for events in larger venues. This is particularly noticeable at open-air venues where the FOH mix position is normally further from the stage than in indoor venues. The effect of poor venue acoustics is illustrated by inspecting two individual sets of event data: one from a venue specifically designed for amplified music events and one designed with little to no consideration for acoustics, as its primary use was as an ice arena (Figure 4.4).

Interestingly, the trend observed for average sound level (LAeq and LCeq) shows a steady decrease with increasing venue capacity. Again, this could be explained as a result of less problematic acoustics in the venues (especially considering that all of the venues above 25,000 capacity are outdoors), but may also be a direct result of the higher live dynamic range of the show. Perhaps a greater live dynamic range results in a lower preferred sound level. This would tie in nicely to previous research, where it was shown that an increased system bandwidth results in lower preferred sound levels[38]. It is also worth considering that nearly all the outdoor events were music festivals, where the act's sound engineer would have less control over the sound system design and operation characteristics as compared to the indoor tour dates.

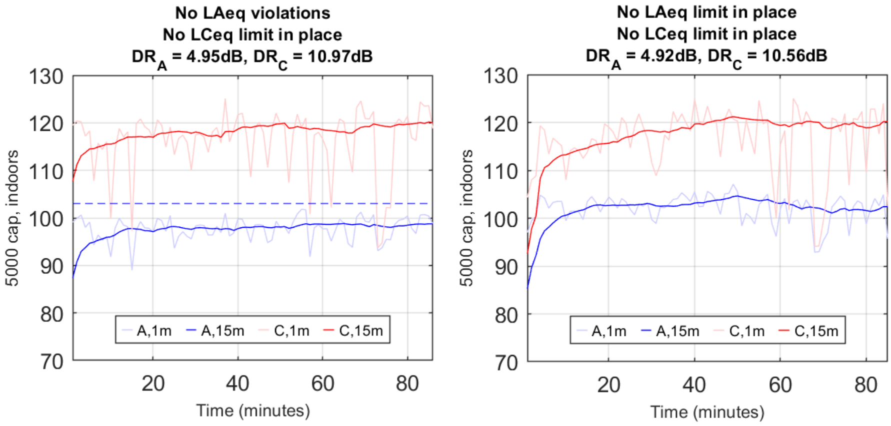

Figure 4.4 Example comparison of individual event data for a venue acoustically designed for amplified music (left) and a venue designed without any acoustical considerations (right).

4.2 LAeq limit

A-weighted equivalent sound level (LAeq) limits are the most encountered regulation at venues across the world at present. The inspected data shows that most of these limits (in place at 53 out of the 130 venues) are in Western Europe, with significantly less sound level regulations in other parts of the world. This is in line with the findings in the previously mentioned AES Technical Document[2]. As a first step in analyzing the effect (if any) of an LAeq limit is to compare the average sound level and live dynamic range between events with and without such regulations (Figure 4.5).

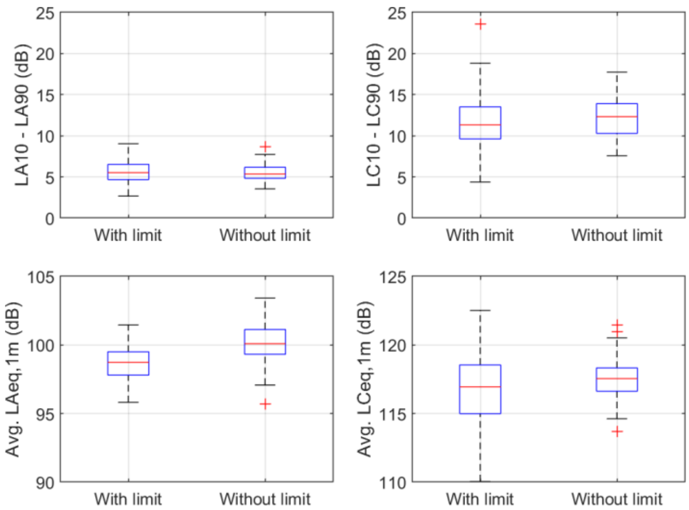

Figure 4.5 L10 – L90 (live dynamic range, in dB) and average Leq,1min (dB) inspected in relation to the presence of an A-weighted equivalent sound level (LAeq) limit

There was only one statistically significant finding within this data, where it was clear that an LAeq limit has a measurable effect on the average A-weighted sound level (LAeq,1min). In this case, the events with a limit in place were approximately 2 dB lower in A-weighted sound level than those without limits in place ($p = 3.25 \times 10^{-9}$). This is as expected and shows that the limits are having some form of effect on the overall level of the event. Critically, the LAeq limit has been shown to have no significant effect on C-weighted sound levels as well as no effect on live dynamic range (A- or C-weighted). This is encouraging, as it gives initial indication that the limit is only affecting sound levels and not impacting the live dynamic range of an event.

In order to further progress this analysis, it was necessary to unpack the data from events with LAeq limits in place to inspect the effect of the two variables within each regulation: level limit and measurement time window (Figures 4.6 and 4.7).

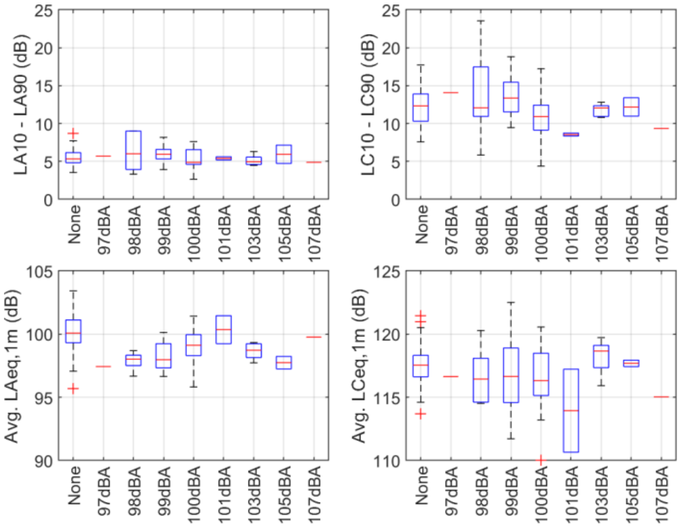

Figure 4.6 L10 – L90 (live dynamic range, in dB) and average Leq,1min (dB) inspected in relation to the specific LAeq limit (dB)

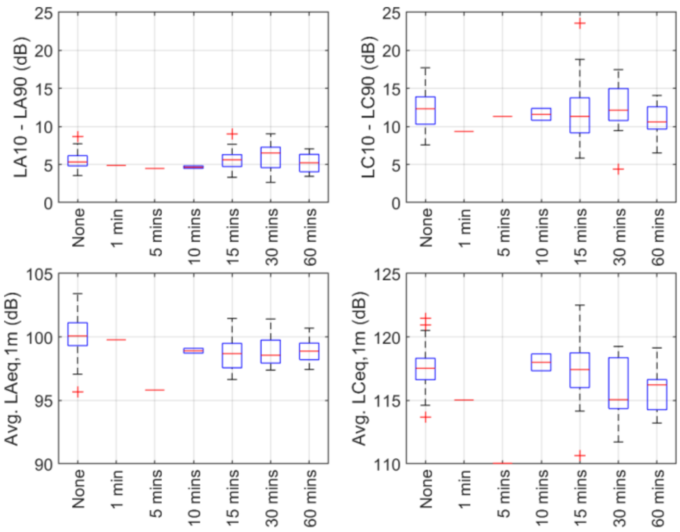

Figure 4.7 L10 – L90 (live dynamic range, in dB) and average Leq,1min (dB) inspected in relation to the specific LAeq measurement time window (minutes)

First, looking at the relationship between the specific LAeq limit and A-weighted average sound level at an event, there is a strong statistical relationship ($p = 1.60 \times 10^{-7}$). For LAeq limits up to and including 101 dBA, the observed average A-weighted sound levels follow the limits (i.e. the data generally clusters around the set limit). Limits set beyond 101 dBA, however, do not indicate a direct relationship to the observed A-weighted sound level. The data shows that events with these high limits result in lower levels as compared to events with limits at or below 101 dBA. One possible explanation is that the sound engineer did not have to worry about complying with a sound level limit during these shows, so mixed in a more relaxed mode, focusing primarily on the musicality of the mix. This is supported by the data from events with no limit in place showing a mean A-weighted level around 100 dBA, which appears to be the natural mix level for this engineer mixing this specific act. The specific LAeq limit did not show any significant effect on the other three inspected metrics.

The LAeq limit on its own does not present a complete picture of the scenario of an event with a sound level regulation in place. The measurement time window can potentially have a critical effect on the impact of the LAeq limit. While there is statistical evidence that the measurement time window has a measurable effect on LAeq,1min and LCeq,1min ($p = 3.76 \times 10^{-7}$ and $p = 7.42 \times 10^{-5}$, respectively), there are no clear observable trends, largely due to the fact that there is no correlation between the

LAeq limit in place and the chosen measurement time window (which, again, is highlighted in the recent AES Technical Document[2]).

There was no statistical significance found in relating live dynamic range (A- or C-weighted) to measurement time window of the LAeq limit. This can be attributed to the sparsity of the data; there are very few data points for measurement time windows of 1, 5 and 10 minutes. Manual observation of the data, however, does indicate that there may be a slight increase in live dynamic range with increasing measurement time window (for both weightings). A potential explanation for this observation again relates to the sound engineer's experience working with the LAeq limit in place. Shorter measurement time windows mean that the engineer has less ability to use dynamics in the overall mix, since the measurement configuration is too sensitive (if dynamics are desired in these cases, the overall level would have to be reduced, which would likely be unacceptable). Longer measurement time windows (15 minutes or more) do not show any noticeable trends, indicating that these time frames allow the engineer to mix with the required dynamics. These trends hold true for both A- and C-weighting, but again, it must be emphasized that the data is sparse, requiring further research to confirm or refute these observations.

4.3 LCeq limit

At the time of writing, LCeq limits are rarely found in place at live events (and virtually non-existent outside of Western Europe), which can be attributed to a lack of unbiased scientific research on the relationship between low-frequency sound exposure at live events to hearing health[1]. Of the 130 events analyzed for this research, only three had LCeq limits in place. This sparsity of data prevented any detailed analysis of LCeq limit level and measurement time window, as was carried out for the LAeq limits. Only a broad analysis of the effect of the presence of an LCeq limit on the metrics under inspection was possible (Figure 4.8).

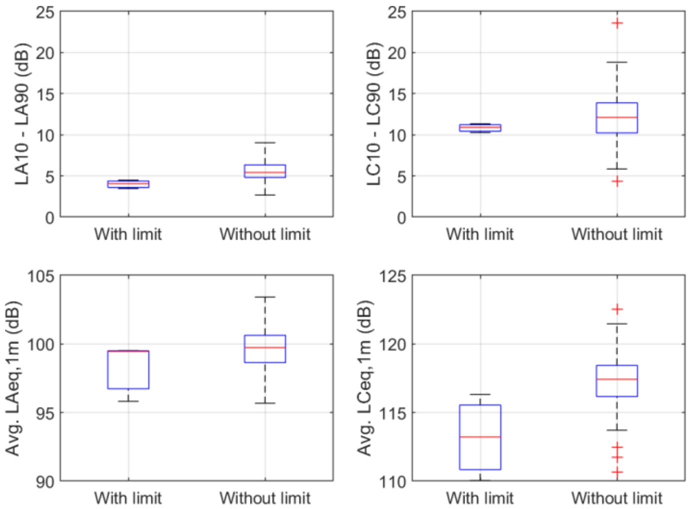

Figure 4.8 L10 – L90 (live dynamic range, in dB) and average Leq,1min (dB) inspected in relation to the presence of a C-weighted equivalent sound level (LCeq) limit

While the analysis was performed on sparse data, it reveals some compelling trends that point to the necessity of further research to explore the effect of LCeq limits in greater detail. First, the A-weighted live dynamic range appears to be strongly influenced by the presence of an LCeq limit ($p = 0.0184$). When an LCeq limit is in place, the A-weighted live dynamic range decreases by approximately 1.5 dB. A similar effect is observed in the C-weighted live dynamic range data, but with much less statistical confidence ($p = 0.424$).

Looking at the average sound levels, the most telling finding is the impact on the average C-weighted sound level. With an LCeq limit in place, the C-weighted sound level was nearly 5 dB lower than at events without an LCeq limit (p = 0.0003). An LAeq limit, for comparison, caused an A-weighted sound level reduction of around 2 dB. LCeq limits were found to have a less significant measured influence on the A-weighted sound levels, but still show roughly a 1 dB lower average A-weighted sound level.

A practical explanation for the reduction in live dynamic range exists. When an LCeq limit is in place, it is regularly the case that this will be the limiting factor in the operation of the sound system. The sound engineer often will struggle to comply with this limit without negatively affecting the entire event's sound. For this data set, the act relied heavily on low-frequency content, therefore any LCeq limit would prove problematic. A result of the sound engineer struggling to stay within the LCeq limit is that the live dynamic range is reduced across all frequencies and the overall A-weighted level is slightly below what is typical of this act's performances. In general, the listening experience is potentially compromised at events with an LCeq limit in place. This is not to say an LCeq limit is not necessary, but it does point to the current limits being arbitrary and unreasonable, largely thanks to the absence of any reliable scientific findings on the subject[2].

5 CONCLUSIONS

Sound level monitoring data collected from 130 events over a five-year span by the same international touring act, mixed by the same sound engineer, was analyzed in respect to an event's average sound level and live dynamic range (A- and C-weighted), resulting in the following summarized findings:

- Tour dates are roughly 1 dB (A and C) louder than festivals. This is likely due a combination of factors including increased familiarity and control of the sound system in conjunction with the acoustic environment (see next point).

- Outdoors events have around 1 dBA greater live dynamic range than indoor events. This could be attributed to the presence of problematic acoustics for indoor venues. There were no observed differences for C-weighted live dynamic range.

- Live dynamic range (A and C) increases with venue capacity. This is almost certainly due to the larger venues in this study being outdoor, so not suffering from acoustical issues, which therefore causes this observation to collapse into the previous point.

- Average sound level (A and C) decreases with venue capacity. This may be due to acoustical issues for the smaller indoor venues (venue acoustics & stage level). This requires further research to verify.

- The presence of an LAeq limit reduces the A-weighted sound level by about 2 dB, but only for events with limits at or below 101 dBA. There is no effect on live dynamic range.

- Short LAeq measurement time windows (below 10 minutes) appear to reduce live dynamic range (A and C). More research is needed, due to the sparsity of the data.

- The presence of an LCeq limit reduces the A- and C-weighted sound levels by roughly 1 dB and 5 dB, respectively.

- The presence of an LCeq limit reduces the live dynamic range (A and C) by approximately 1.5 dB. This is likely due to the sound engineer struggling to maintain compliance with the LCeq limit.

Overall, this research should be considered a starting point to obtain a robust understanding on the effect sound level regulations have on the work of a sound engineer at a live event. The data has revealed some interesting trends, however, that the authors hope will inspire further collaborative research in the area to lead to a long-term goal of developing practical, effective and safe live event sound level regulations, acceptable to all key stakeholders.

6 REFERENCES

1. World Health Organization. Make Listening Safe initiative. https://www.who.int/activities/making-listening-safe
2. Hill, A.J. (editor). “Understanding and managing sound exposure and noise pollution at outdoor events.” AES Technical Document AESTD1007.1.20-05. May 2020.
3. Kok, M. "Sound Level Measurements & Control at Large Dance Events." Audio Engineering Society Conference: 58th International Conference: Music Induced Hearing Disorders. Audio Engineering Society, 2015.
4. McGinnity, S.; J. Mulder; E.F. Beach; R. Cowan. "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. Audio Engineering Society, 2018.
5. Hill, A.J.; J. Mulder; M. Kok; J. Burton; A. Kociper; A. Berrios. A case study on sound level monitoring and management at large-scale music festivals. Proc. Institute of Acoustics – Conference on Reproduced Sound, Bristol, UK. November, 2019.
6. Vanguardia. "Victorious Festival - Concert Noise Assessment and Noise Management Plan, VC-101551-REP01." March, 2014.
7. Mercier, V., D. Luy, and B. W. Hohmann. "The sound exposure of the audience at a music festival." Noise and Health 5.19 (2003): 51.
8. Ramakers, G.G.; V.J. Kraaijenga; G Cattani; G.A. van Zanten; W. Grolman. "Effectiveness of earplugs in preventing recreational noise–induced hearing loss: a randomized clinical trial." JAMA Otolaryngology–Head & Neck Surgery 142.6 (2016): 551-558.
9. Beach, E.F.; J. Mulder; I. O'Brien. "Development of guidelines for protecting the hearing of patrons at music venues: Practicalities, pitfalls, and making progress." Audio Engineering Society Conference: 2018 AES International Conference on Music Induced Hearing Disorders. Audio Engineering Society, 2018.
10. Ordonez, R.; D. Hammershoi; C. Borg; J. Voetmann. "A pilot study of changes in otoacoustic emissions after exposure to live music." Audio Engineering Society Conference: 47th International Conference: Music Induced Hearing Disorders. Audio Engineering Society, 2012.
11. Tronstad, T.V. "Hearing Measurements During Two Norwegian Music Festivals." Audio Engineering Society Conference: 58th International Conference: Music Induced Hearing Disorders. Audio Engineering Society, 2015.
12. Opperman, D.A.; W. Reifman; R. Schlauch; S. Levine. "Incidence of spontaneous hearing threshold shifts during modern concert performances." Otolaryngology—Head and Neck Surgery134.4 (2006): 667-673.
13. World Health Organization. "Environmental noise guidelines for the European Region." (2018).
14. Guski, R,; D. Schreckenberg; R. Schuemer. "WHO environmental noise guidelines for the European region: A systematic review on environmental noise and annoyance." International journal of environmental research and public health 14.12 (2017): 1539.
15. Poulsen, T.; F.R. Mortensen. "Laboratory evaluation of annoyance of low frequency noise." Working report 1 (2002).
16. Hellman, R.; N. Broner. "Relation between loudness and annoyance over time: Implications for assessing the perception of low-frequency noise." The Journal of the Acoustical Society of America 115.5 (2004): 2452-2452.
17. Segura, J.; F. Santiago; M. Cobos; A. Torres; J.M. Navarro. "Psychoacoustic Annoyance Monitoring with WASN for Assessment in Urban Areas." Audio Engineering Society Convention 138. Audio Engineering Society, 2015.

18. Bradley, J.S. "Annoyance caused by constant-amplitude and amplitude-modulated sounds containing rumble." Noise Control Engineering Journal 42.6 (1994): 203-208.
19. Begault, D.R. NASA/TM—2018–219748. Assessment and Mitigation of the Effects of Noise on Habitability in Deep Space Environments: Report on Non-Auditory Effects of Noise. January 2018.
20. Zhao, F.; V.K. Manchaiah; D. French; S.M. Price. "Music exposure and hearing disorders: an overview." International journal of audiology 49.1 (2010): 54-64.
21. Castelo-Branco, N.A. Low Frequency Noise: A Major Risk Factor in Military Operation. Center for Human performance Alverca (Portugal), 2003.
22. Leventhall, G.; P. Pelmear; S. Benton. "A review of published research on low frequency noise and its effects." (2003).
23. Leventhall, G. "Low Frequency Noise. What we know, what we do not know, and what we would like to know." Journal of Low Frequency Noise, Vibration and Active Control 28.2 (2009): 79-104.
24. Salansky, N.; A. Fedotchev; A. Bondar. "Responses of the nervous system to low frequency stimulation and EEG rhythms: clinical implications." Neuroscience & Biobehavioral Reviews 22.3 (1998): 395-409.
25. Johnson, D.L. The effects of high level infrasound. No. AFAMRL-TR-80-13. AIR FORCE AEROSPACE MEDICAL RESEARCH LAB WRIGHT-PATTERSON AFB OH, 1980.
26. Dibble, K. "Hearing loss & music." Journal of the Audio Engineering Society 43.4 (1995): 251-266.
27. Tronstad, T.V., and Femke B. Gelderblom. "Sound exposure during outdoor music festivals." Noise & health18.83 (2016): 220.
28. Jerger, J.; B. Alford; A. Coats. "Effects of very low frequency tones on auditory thresholds." Journal of speech and hearing research 9.1 (1966): 150-160.
29. Patterson, J.H., et al. "Temporary threshold shift in man resulting from four-hour exposures to octave bands of noise centered at 63 and 1000 Hz." The Journal of the Acoustical Society of America 62.S1 (1977): S95-S96.
30. Petrescu, N. "Loud music listening." McGill Journal of Medicine: MJM 11.2 (2008): 169.
31. Raichel, D.R. "Recreational Noise Exposure-An Occupational Hazard for Audio Engineers." Journal of the Audio Engineering Society 28.12 (1980): 896-899.
32. Thepurpleguide.co.uk. (2019). The Purple Guide. [online] Available at: https://www.thepurpleguide.co.uk/ [Accessed 12 Mar. 2019].
33. Keppler, H.; D. Ingeborg; D. Sofie; V. Bart. "The effects of a hearing education program on recreational noise exposure, attitudes and beliefs toward noise, hearing loss, and hearing protector devices in young adults." Noise & health 17.78 (2015): 253.
34. Wilson, G.L. "Am I Too Loud? (A Symposium on Rock Music and Noise-Induced Hearing Loss)." Journal of the Audio Engineering Society 25.3 (1977): 126-150.
35. Wilson, G.L. "Entertainment Noise: A Hearing Hazard." Journal of the Audio Engineering Society 24.2 (1976): 121-121.
36. Behr, A.; Brennan, M.; Cloonan, M. “The Cultural Value of Live Music from the Pub to the Stadium: Getting Beyond the Numbers.” University of Edinburgh, University of Glasgow (2014).
37. Navne, J. “Sound level measurements made eazy: 10EaZy – Intuitive SPL monitoring for live sound events.” AES 58th International Conference. June 28-30, 2015.
38. Burton, Jonathan G., Damian T. Murphy, and Jude S. Brereton. "Perception of Low Frequency Content of Amplified Music in Arenas and Open-Air Music Festivals." Audio Engineering Society Conference: 2017 AES International Conference on Sound Reinforcement–Open Air Venues. Audio Engineering Society, 2017.