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Sound Level Measurement, Monitoring and Management in Small Music Venues: Leq Averaging Time Interval

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ABSTRACT

This paper considers different Leq averaging time intervals and their effect on the dynamic range of live music as presented to an audience. Data was collected in four small and mid-sized music venues in Perth, Australia in 2019, and combined with an earlier data set recorded in similar venues in Melbourne in 2016. Sound Pressure Level (SPL) data was collected at the Front of House (FOH) sound mixing desk location. In the first phase (control) data was recorded without giving the sound engineer access to sound level information. In the second, phase (experimental), the sound engineer did have visual access to the real time data. This study was designed as a follow-up to earlier work that took place in six music venues in Melbourne [1]. That study concluded that the availability of real time measurement data to sound engineers at the mixing desk can help to keep sound levels below a set maximum. That study also pointed out that if a reduction of the sound exposure of audience and staff is sought, rather than adhering to a prescribed maximum level, more specific choices in terms of level and Leq time interval should be made. Two research questions are considered in this paper, one focused on the impact of the Leq averaging time interval on dynamic range and a second question considering whether set maxima can inadvertently increase the sound levels of performances that would ordinarily be lower than a set maximum level.

1 Introduction

Music venues are unique musical and acoustic ecosystems, and no two performance spaces or two concerts are the same. Even a comparison of two different nights within the same venue, with the same band or act playing the same songs can be problematic, for instance due to the size and response of the audience, or simply changes in temperature and humidity. On top of that, smaller performance spaces operate on a great range of governance models and budgets, from community owned venues run by volunteers to purpose built professional facilities for profit or not for profit, with or without external funding.

2 Outlook on hearing damage risks

With growing awareness of the role of entertainment noise as a contributing cause to hearing damage, several countries have introduced legislation or guidelines to support venues in reducing the exposure of their audiences, staff, and performers. A recent addition in this problem space is the World Health Organisation (WHO) “global standard for safe listening venues and events” [2]. Enforcement and monitoring of sound pressure levels (SPL) requires adequate and reliable sound pressure level measurement and monitoring tools as well as staff that can operate these tools, interpret the data and act in accordance.

3 Measurement protocols

When considering the great variation between venues and performances outlined above it becomes clear that objective evaluation of SPL data, and enforcement of legislated or agreed levels is hindered by numerous challenges. The few countries that have introduced legislation or guidance with respect to an observable maximum SPL all take slightly different approaches, with different Equivalent Continuous Sound Level (Leq) values and averaging time intervals. Measurement protocols also vary, for instance, in some countries the measurement microphone is required to be positioned at FOH, the distance of which to the stage and PA can of course vary greatly [3-5]. In other examples (Germany, UK) measurements should take place at the loudest part of the venue accessible to the audience. That last approach is challenging for smaller venues where not a lot of distance can be created between the loudspeakers and audience. In the WHO standard a third approach is foreseen, with the microphone in the geometric centre of the audience space, based on a measurement protocol developed in the Netherlands.

3.1 Leq Averaging Time Intervals

Different values are in use across Europe in the different regulatory and voluntary frameworks [5], ranging from 100dB $L_{Aeq,60min}$ in Switzerland, 99dB $L_{Aeq,30min}$ in Germany and Norway to 103dB $L_{Aeq,15min}$ in the Netherlands. For live sound engineers touring in Europe this is impracticable and perhaps even strange given that hearing physiology does not change when crossing a border. The new WHO standard proposes 100dB $L_{Aeq,15min}$, which potentially could help align differences, although for some countries this will bring a substantial reduction, for instance in the Netherlands were currently 103dB $L_{Aeq,15min}$ is the maximum. Here it is important to mention that neither the WHO standard nor any of the existing measures are considered safe, and the wearing of suitable hearing protection is always recommended.

4 Data collection

Study M took place in Melbourne in 2016/17 and the follow up Study P in Perth (2019/20). Given that there are no official guidelines in place in Australia there is no infrastructure in place to centrally monitor levels and most venues don't own or have access to a sound level meter, nor is there an official set limit (other than those covered by local environmental noise regulations). Consequently, temporary systems needed to be installed and removed every night. A laptop, audio interface and microphone were installed at FOH prior to each concert. This ad hoc approach hindered accurate data collection, making it clear that whether for research or for enforcement fixed installations are preferable. The 10EaZy system[1] in use requires an internet connection to send out a report via email after each concert. From 2018 this system was upgraded with the ability to output SPL data for every second, unfortunately this was not part of the automated email report and per second data had to be collected manually. For Study P a research assistant was employed to copy and back-up the data from the laptops. Nevertheless, data collection failed at several instances, particularly impacting the ability to use the much more accurate per second data in the data analyses.

4.1 Maximum Average Manager (MAM)

A key feature of the 10EaZy software interface is a horizontal line of six green and six red segments called the Maximum Average Manager (MAM). The MAM projects how much headroom is left in green, or by how much the set Leq has been violated in red. The interface responds to a set L_{Aeq} and time interval, usually 5, 15 or 60 minutes. This is a familiar interface for many operators and most common software applications designed for this purpose use a similar tool.

5 Research Question One

One of two questions to emerge from Study M concerns the time interval used to calculate the continuous equivalent sound level in the real time monitoring system. In the Melbourne study a 15-minutes interval was used. This was chosen as it is in use in several European countries to express L_{Aeq} maxima [5]. Anecdotal feedback from live music sound engineers often indicates a preference for a 5-minutes L_{Aeq} interval, as that is closer to the average duration of a pop song. The question of operators' preference for a specific Leq time averaging interval was a topic in a global survey [4, 6] that took place in 2020. According to the survey response 15-minutes was preferred over other integration times with 5-minutes shown to be popular as well. At the same time, it is generally understood that shorter integration times for Leq monitoring make working with musical dynamics more challenging. Building on that heuristic the first research question is:

What is the effect of shorter L_{Aeq} averaging periods on dynamic range? (Q1).

5.1 Research Question Two

Study M looked at the effect of the use of real time sound level information, using commercially available technology, on the audience exposure to dangerously loud sound. Data analysis observed a levelling effect related to the introduction of a monitored maximum sound level. The data showed that the maximum level could inadvertently be seen as a target that should be met, resulting in an increased sound level and a reduction in dynamic range (this issue was also addressed in [7]). This levelling

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[1] Version 2.8, SG software, Denmark, 10eazy.com.

effect, or “level creep”, informs the second question in this paper:

What is the effect of the use of real time sound level monitoring on $L_{Aeq,T}$ and dynamic range? (Q2).

5.2 Dynamic Range

The importance of dynamic range (DR) in live music is well understood as it allows for dynamic and exciting shows, with the potential for one song to be the loudest song (usually the encore). Anecdotally, there are indications that some EDM producers and performers of some of the harder metal genres prefer a consistent sound with very little changes in dynamics over the duration of a show. For the context of this paper those are understood as exceptional. More generally, an argument can be made that a well-informed approach to the dynamic range of a whole concert can play a role in the reduction of audience sound exposure. In the context of pop and rock music there are several ways to derive the DR of a concert [8]. Interpreting it as the difference between the lowest (empty venue) and the highest SPL is not that useful when concerned with audience exposure. A more relevant value would be the difference between the lowest (audience present, band not playing) and the highest (band playing) SPL. This is derived from the A-weighted L97-L10, or, the $L_{Aeq,1min}$ that occurs 10% of the time minus the $L_{Aeq,1min}$ that occurs 97%. In this paper we will refer to this metric as DRA. A second approach is to calculate the same value only when the band is playing, with the breaks in between songs filtered out. As shown in [8] this value, referred to LDRA is calculated much more reliably from per-second data, and because of missing data LDRA is left out of this analysis.

6 Study P

For Study P, daily reports were generated that provided A and C weighted Leq values for 1, 5 and 60 minutes. Other values reported were L_{Cpeak}, L_{ASlow} and $L_{AFast.}$ These were not used in this analysis. Prior to data processing, the timeline for each night was inspected visually in Excel, and data before concerts and after concerts was manually removed. This way, common elements such as soundchecks and music post-concert (i.e. from a DJ) were excluded given that the intervention targeted operation at the FOH mixing desk. A Matlab[2] script was used to read the maximum Leq values for each night, the $L_{Aeq,T}$ (T indicates for the duration of an event or concert) was derived as described in study M [1] and DRA and DRC were calculated according to [8]. The Matlab script created a spreadsheet with all these values, one row for each night, which was manually coded for each venue and between the control (phase 1) and experimental (phase 2) conditions. For the statistical analyses the open-source package JASP[3] was used.

6.1 Study P, Venue A (PA)

Venue PA was (it closed due to the 2020 Covid-Sars19 pandemic) a small inner-city venue with a small stage. In the control phase data was successfully collected for *n*=15 nights and *n*=18 nights in the experimental second phase. For the latter the MAM was set to 100dB $L_{Aeq,\ 5min}$. A small but not significant increase in $L_{Aeq,T}$ was observed in the experimental phase. Significant reductions were observed for $L_{Ceq,5min}$ and $L_{Cpeak,}$ but with the MAM

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[2] MATLAB version: 9.13.0, Natick, Massachusetts

[3] JASP (2023, Version 0.17.3)

interface responding to A-weighting these cannot directly be related to the intervention.

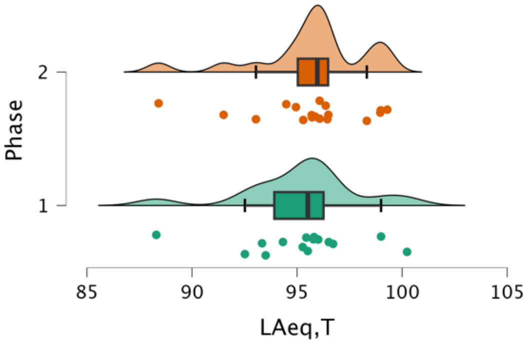

Figure 1 PA: $L_{Aeq,T}$ for each phase.

The DRA stayed virtually the same between the two phases but without any significant changes in L_{Aeq} (Figure 1) these outcomes are not relevant for either of the questions in this study.

6.2 Study P, Venue B (PB)

The second venue in Study P is a popular, small urban venue, which at the very start of the project was issued with a low frequency noise complaint from a nearby home, threatening the venue's license. In response it was decided to finish the first phase sooner than planned (*n*=14, *n*=27 for phase 2), to allow the venues' operators to adhere to a strict low frequency maximum of 109dB $L_{Ceq,\ 5min}$. This was realised by setting the MAM to 99dB $L_{Aeq,\ 5min}$, informed by the heuristic that in pop and rock music (this is very much a rock venue) the average difference between A and C weighted SPL is 10dB. Because the sample size of the first phase was smaller than 25 and the assumption of normal distribution was not met, non-parametric testing was used to test for the significance of this finding. A very small reduction in $L_{Aeq,1min}$ found in the experimental phase turned out to be insignificant (U=58.5, p=0.25), as was a 1dB reduction in $L_{ACeq,5min}$ (U=234.0, p=.221). However, as can be seen in Figure 2 in phase two the values for $L_{Ceq,5min}$ stayed close to the set maximum of 109dB. These outcomes suggest the intervention contributed to the resolution of the noise complaint, which was resolved in the same interval. As with venue PA these outcomes have no bearing on Q1 or Q2.

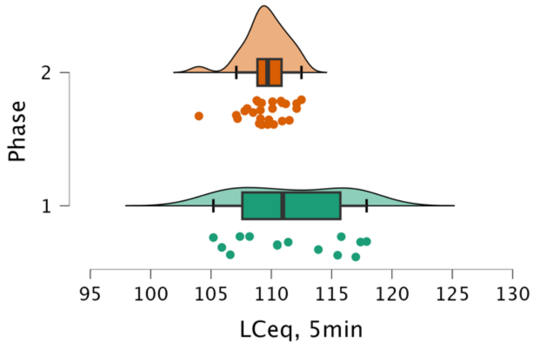

Figure 2 PB: LCeq, 5min for each phase.

6.3 Study P, Venue C (PC)

Venue PC is a middle sized, urban venue which is used for live music and dance nights as well as local school band concerts and trivia nights. Data (Figure 3) was collected over *n*=20 nights in the control phase and *n*=28 in the experimental phase, with the MAM set to 102 dB $L_{Aeq,5min}$.

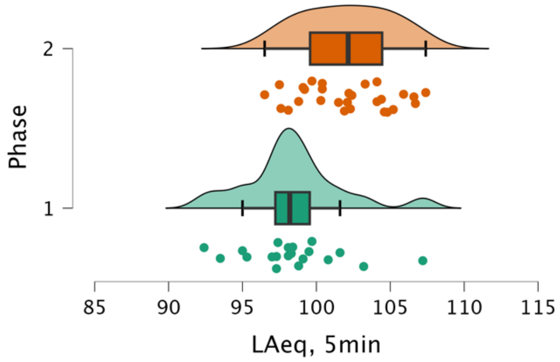

Figure 3 PC: $L_{Aeq,5min}$ for each phase.

That value was chosen on the senior operator's insistence, even though the phase 1 data indicated a lower value would have been more appropriate with 98dB as the average for $L_{Aeq,5min}$. The operator's concern was that some of the better-known acts that were booked to perform during phase 2 would object. Perhaps because of this MAM setting, the levelling effect can be clearly observed in the data collected in this venue. All the L_{Aeq} and L_{Ceq} parameters recorded increased in the experimental second phase. $L_{Aeq,5min}$ was almost 4 dB higher (T=-3.972, p<.001) as was $L_{Aeq,60\ min}$ (T=-3.21, p<.001). The DRA showed a small, but insignificant, increase just below 1dB (Figure 4).

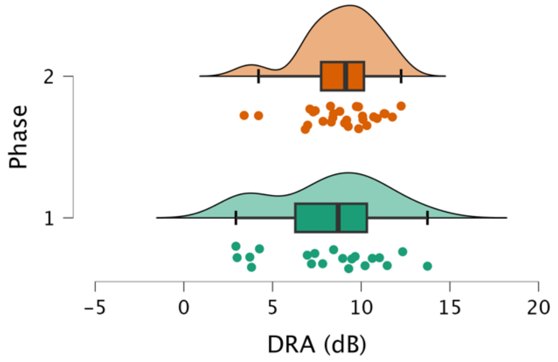

Figure 4 PC DRA for both phases.

After data the collection interval the senior operator of the venue was informed of this outcome and the MAM value was reduced to 98dB $L_{Aeq,5min}$, in line with the levels recorded in the first phase.

6.4 Study P, Venue D (PD)

Venue D is a middle-sized venue in the Perth CBD generally catering for heavy metal concerts. In this venue n=25 nights were recorded in the control phase and n=43 in the experimental phase, with the MAM set to 103dB $L_{Aeq,5min}$ (Figure 5).

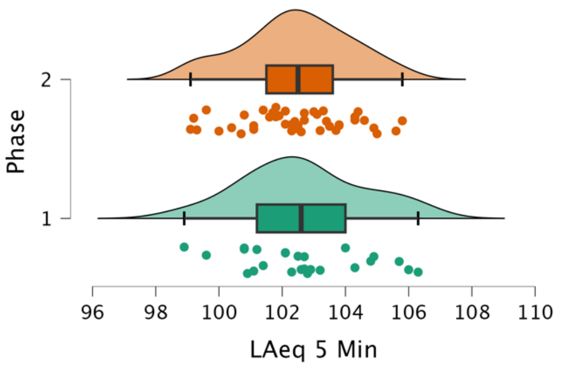

Figure 5 PD: $L_{Aeq,5min}$ for each phase

No significant changes between phases were observed in any of the L_{Aeq} parameters. Reductions were seen in the C-weighted parameters and consequentially in the C-weighted Dynamic Range: $L_{Ceq,5min}$ was 2dB lower (Welch test, T=3.194, p=.002). However, the venue's senior operator did indicate that changes were made to the LF sound system and as such we can't be sure if the use of the SLM system caused this change.

7 Revisiting Study M

Using the new [8] methods to establish DR it's worthwhile revisiting the analysis of the data collected in study M. The analysis in [1] shows that three out of six venues operated at a lower SPL, opting for a MAM setting of 98 or 99dB $L_{Aeq,15min}$. The second, louder, group of three opted for a higher MAM setting of 103dB $L_{Aeq,15min}$.

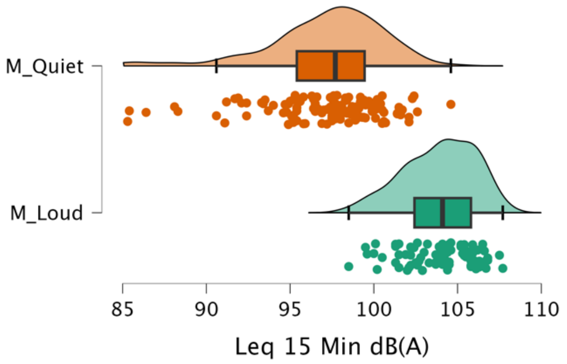

Figure 6 $L_{Aeq,\ 15min}$ grouped venues in Study M

To consider the effect of the intervention on dynamic range the venues are separated into a quiet (*n*=128) and a loud group (*n*=78), Figure 6. Of note is that for the Quiet group the DRA was significantly greater by 2dB (T=-5.794, p<.001) (Figure 7).

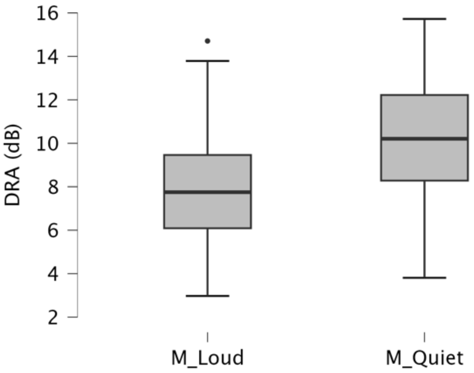

Figure 7 DRA grouped venues in Study M

In the second phase (Figure 8) the group of three quieter venues showed an increase of $L_{Aeq,15min}$ by 1.5dB (T=-2.305, p=.023) and significant reductions were observed in all the recorded Leq parameters. This is the clearest indication of the issue of level creep (Q2) in this study.

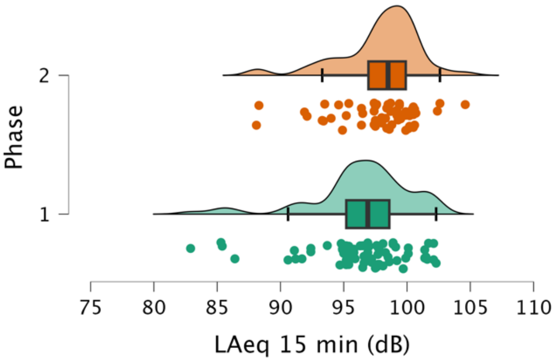

Figure 8 Study M, within quiet group, $L_{Aeq, 60min}$

The DRA showed a minute reduction between phases, statistically not significant. For the three louder venues in Study M no significant changes were observed in Leq parameters or DRA.

8 DR and averaging intervals: 5 vs 15 minutes

Study P was set-up using a 5-minute Leq averaging interval, to compare the outcomes with the 15-minute Leq integration time of Study M. Data from the second phase (operators could see the real time MAM display) were compared, with dataset M using Leq interval of 15 minutes (*n*=133) and 5 minutes (*n*=90) in dataset P (Figure 9)

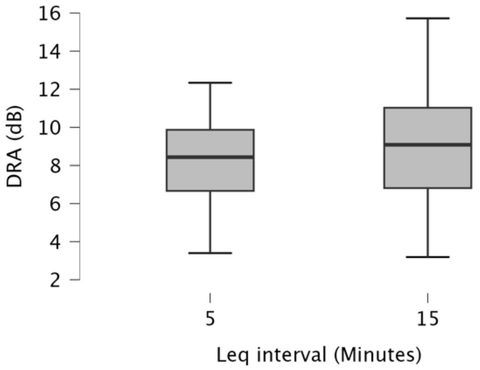

Figure 9. DRA, 5 vs 15 minutes.

A Welch T-test (T=-2.247, p=.026) indicates that the difference in mean is significant and the DRA when using a 5-minute interval is just short of 1 dB lower than when using a 15-minutes interval.

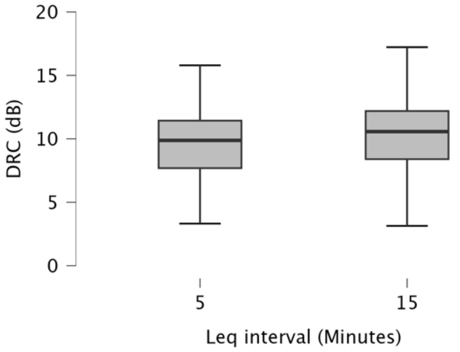

Figure 10 DRC, 5 vs 15 minutes.

The C-weighted DR, DRC showed a similar difference (Figure 10, Welch T-test (T=-1,744, p=.041).

8.1 DR and Crest Factor

To compare the application of different Leq time intervals, DR is a key consideration. A practical example is found in Flemish Belgium where the legislated limit is 100dB $L_{Aeq,60min}$. In practice, also legislated, this limit is observed as 102dB $L_{Aeq,15min}$ which is, within that specific legislation, considered equivalent to the 60 minutes value. In the real world the numerical relation between the two is very much dependent on the DR and is rarely exactly 102-100= 2dB.

8.2 Comparing different Leq Intervals

When considering a mathematical model to predict an equivalent level for different Leq intervals we can use the Crest Factor (CF). CF expresses the difference over time between the RMS and peak of a complex sound wave. In live sound a theoretical CF of 2.6 is considered appropriate, corresponding to a theoretical dynamic range of 8.4dB [9]. However as observed above, different Leq intervals detect different values for DR and therefore will also have a different CF. To consider level equivalence between different averaging time intervals we need to know the CF for each interval. CF for four different was derived from a large dataset used in an earlier study [8] (Table 1).

Leq time (min)	**CF**
60	2.1
30	2.3
Theory	*2.6*
15	2.8
5	3.9

Table 1 CF for different Leq intervals derived from (different) measurement data.

More analysis is needed to calculate these values with greater accuracy but for the context of this paper these values give a good indication. Equation (1) calculates the equivalence between two different Leq intervals, expressed as CF.

$$L_2 = 10\log_{10}\left(\frac{CF_2 * 10^{\frac{L_1}{10}}}{CF_1}\right) \quad (1)$$

This equation can be used to derive, for instance, equivalences for the maximum sound level of 100dB $L_{Aeq,15min}$ in the WHO standard (Table 2).

WHO Standard		**Equivalence**	
L1 (dB)	**T1 (min)**	**T2 (min)**	**L2 (dB)**
100.0	15	5	101.5
100.0	15	30	99.3
100.0	15	60	98.8
100.0	*60*	*15*	*101.2*

Table 2 Examples of L2 derived using Equation 1. Bottom row shows equivalence between 60 and 15 minutes as used in Flemish Belgium.

These values can now be compared with the average Leq observed in the second phase of Studies P and M, to see whether they comply with the WHO standard (Table 3).

	MAM	$L_{Aeq,5m}$	$L_{Aeq,60m}$	$L_{Aeq,T}$
WHO	n/a	**101.5**	**98.8**	n/a
PA	*100*	100.5	97.9	95.7
PB	*99*	99.7	96.6	93.4
PC	*102*	102	99.5	96.2
PD	*103*	102.5	99.9	97.3
MA	*103*	103.5	102.1	99.2
MB	*103*	102.8	100.8	98.6
MC	*98*	96.4	93.9	92.4
MD	*98*	97.5	96.2	93
ME	*99*	98.6	96.6	94
MF	*103*	104.9	103.3	100.3

Table 3 Study M data compared to WHO Standard, shaded cells indicate average below 100dB $L_{Aeq, 15min}$. Note MAM time is 5 min in P, and 15 min in M.

Averaged over phase 2 half of the venues were compliant at the time of data collection, and, again on average, stayed below the MAM setting that was selected.

9 Conclusions

This paper provides a better understanding of the relation between integration time and dynamic range. Greater knowledge of the interaction between the two is important to inform discussions about what metrics to use when setting levels in the context of an individual venue, a multiday festival or for an entire jurisdiction, by way of guideline or legislation. On top of that, the global roll out of the WHO standard and 100dB $L_{Aeq,15min}$ as maximum will raise the question how that value relates to maxima currently in use.

Study M was initiated to start creating an evidence base for the use of real time sound level monitoring systems in small music venues, stemming from the desire of a reduction in audiences' exposure to dangerously loud sounds. The ensuing Study P was designed to further test the hypothesis that the use of such systems brings the risk of an increase of levels at concerts that would ordinarily be not very loud. The analysis in this paper focussed on two questions to do with dynamic range, firstly the effect of shorter Leq averaging interval on DR. With respect to this first question the analysis of the data collected in Phase 2, with a 15-minutes integration in Study M and 5-minutes in Study P, shows a statistically significant relation between (shorter) integration times, and (lower) dynamic range. As observed in [8] dynamic range is an important aspect of live music that contributes to audiences' excitement, the question remains however if this small reduction affects the experience.

The second question investigates the effect of the use of real time SPL monitoring tools on audience exposure specifically concerning the possibility of 'level creep'. The data collected in venue PC, and the analysis of the three quieter venues in Study M support this hypothesis, even though the many limitations of in-situ data collection must be kept in mind. This outcome adds support to the conclusion of Study M that flexibility is needed for venues in choosing maximum Leq level and averaging interval, within the boundaries of enforceable legislation or the WHO standard. A one size fits all approach risks avoidable increases in audience exposure at concerts that would be relatively quiet with no monitoring in place. As a general tendency in these two studies, it is important to note that the average DRA was statistically the same across both phases and there is no indication that 'level creep' is necessarily accompanied by a reduction in DR.

Data collection was challenging in both studies, due to the ad-hoc nature of the measurement gear. Dedicated fixed and networked installations, as found for instance in those countries where legislation has been introduced, is important for adequate real time monitoring as well as post-hoc evaluation. When data is collected centrally it is important that this happens with a per-second accuracy as this enables much more accurate analysis. To illustrate, this final graph shows the LDRA reduction in PB (the only venue with per-second data available for all nights) as well as the difference in distribution between phases. The reduction (0.9dB) was significant (U=238.0, p=0.036), see Figure 11.

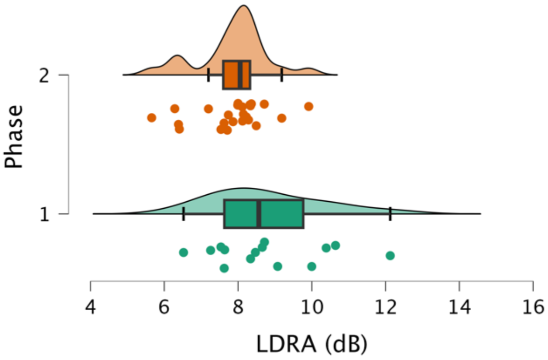

Figure 11 PB: LDRA derived using per-second data.

10 Future work

This study raises the question whether the increased accuracy of the LDRA parameter can provide greater insight into the relation between DR and the use of real time monitoring. More work is needed to increase the accuracy of the CF for the common integration times by analyzing large datasets, for instance those collected in countries where this data is collected centrally.

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