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A case study on practical live event sound exposure monitoring

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ABSTRACT

The recently launched WHO Global Standard for Safe Listening Venues and Events aims to make listening safer and more enjoyable for audiences around the world. Some key questions remain on how to practically monitor sound exposure as well as on how patrons' hearing may be affected after significant exposure. This paper presents a case study where various sound exposure monitoring systems and methods were trialed in an indoor music venue. The aim of the work was to develop and validate a practical, accurate and repeatable technique to track sound exposure across music venues that can be presented in real-time. Results indicate that this can be achieved with no more than four, and as few as two, sound level monitoring locations alongside fixed calibration measurements and a small number of spot measurements at the mix position during a performance.

1 Introduction

Hearing health has become difficult to ignore in the live event industry. There are regular reports in the mainstream media covering stories about musicians who have had to take a step back from performing, or to retire from touring completely, due to fears that they could lose their hearing if they continue as usual. While many countries have occupational noise regulations that should notionally protect musicians, outside of Europe there are extremely few examples of regulations to protect audience members from excessive sound levels.

While there has been recent movement towards standardizing such a limit (as discussed in Section 2), what is clear is that there is a distinct lack of useful long-term data on audience and musician sound exposure at live events. This paper details a pilot study aimed at developing an adequately accurate and practical method for monitoring sound exposure at live events. The study was carried out in a single venue, where three sound level monitoring systems were trialed, each featuring measurement sensors at four fixed locations within the venue. An important focus of the work was to develop a system that kept hardware and calibration requirements to a minimum.

Relevant background information is covered in Section 2, followed by a detailed description of the methods for this study in Section 3, including details of the venue, sound monitoring systems, and data analysis procedures. The results are presented in Section 4, with the paper concluded in Section 5.

2 Background

A recent AES technical document [1] expressed in no uncertain terms that sound engineers have a duty of care to anyone who is being exposed to sound energy emitted from the sound systems under their control. This, of course, raises the question of what the sound exposure limit should be for audience members at live events. The same technical document reviewed all available audience sound exposure limits across the globe and found little consistency between them.

The WHO's Make Listening Safe Initiative made this ambiguity a focus which led to the publication of the WHO Global Standard for Safe Listening Venues and Events [2]. The standard defines the audience sound exposure limit as 100 dB $L_{Aeq,15min}$, as measured at a reference location. Following [3], the reference location is typically at the center of the core audience area, where sound levels are expected to be representative of those to which a majority of the audience is exposed. The standard notes that there is evidence that even if such a limit is adhered to, it does not eliminate the danger of hearing damage.

While the WHO has noted in a recent publication [4] the distinct lack of unbiased scientific research in this area, there is a small collection of published studies that provides insights into the problem at hand [5-13]. The difficulty with many of these studies is that any data collected on the actual impact on musicians' or audience members' hearing is only a snapshot, as longitudinal studies are extremely difficult in this area. This results in ambiguity regarding sound exposure limits, especially in relation to low-frequency exposure, where there is virtually no relevant published data that would allow for a well-defined limit. This is despite it being shown in previous work that audience members nearest to a ground-based subwoofer system can be exposed to levels greater than 140 dB $L_{C,peak}$ [14].

3 Method

While this work doesn't provide a fully validated methodology necessary to launch a longitudinal study, it does present a possible solution for real-time continuous sound exposure monitoring.

3.1 Venue

The venue used for this pilot study was Metronome, part of Nottingham Trent University, UK. The venue is used for a variety of performances, from popular music to standup comedy. The venue (11.0 m x 17.2 m x 4.3 m) has a 400-person capacity (standing), as well as a seated configuration (which wasn't considered in this research due to time constraints), with a medium-format line array sound system. The venue was purpose built, with absorption and diffusion panels across the ceiling and side walls. There is no specific low frequency absorption in the venue, which results in unoccupied $T_{30(63Hz)}$ and $T_{30(125Hz)}$ of 1.03 and 0.78 seconds, respectively. The Schroeder frequency of the unoccupied venue is 72 Hz, resulting in perceptual modal effects occurring below this frequency. The mid-high frequency range, the area of most interest for sound exposure, has a $T_{30(500Hz\text{-}4kHz)}$ of 0.55 seconds, comparable to recommendations for such venues [16]. The venue was selected for this study due to ease of access, as one of this paper's authors is employed by the university, thus providing full flexibility in the deployment of sound monitoring equipment.

3.2 Monitoring systems

Three commercially available sound level monitoring systems were selected for this work. For the purposes of this paper, the systems will remain anonymous, being referred to as Systems A, B, and C.

System A logs sound levels as $L_{Aeq,1sec}$. The meters are uncalibrated and powered by 3 AA batteries and connected to a hub. The hub is designed to connect via WiFi, although at the time of the testing this wasn't possible to set up. As a workaround, the hub was opened to access its ethernet port to allow for a wired connection. Logged data is accessed through Google Cloud, although data visibility is controlled by the company's technical team, with a roughly one day delay before the data is visible.

System B logs sound levels as L_{Aeq} and L_{Ceq} in user-defined time frames, down to one second. The meters are Class-2 factory calibrated and powered through an internal battery and a micro-USB connection, and wirelessly connected to a hub. The hub requires a wired internet connection. Logged data is accessed through the company's bespoke data portal, allowing for flexibility in data formatting and presentation.

System C logs sound levels as L_{Aeq}, L_{Ceq} and in 1/3 octaves, all with a base time frame of one minute. The meters are MEMS-based meeting Class 1 requirements and are factory calibrated, powered through an internal battery and a DC barrel connector with a screw lock. The meters connected directly to WiFi (configured using a smartphone) but also can connect to the local 4G network if the WiFi fails. Logged data is accessed through the company's bespoke data portal, allowing for flexibility in data formatting and presentation.

3.3 Deployment

Four meters for Systems A, B and C were acquired and deployed to four locations along the grid affixed to the ceiling of the venue (Figure 3.1):

1) Center stage
2) Center audience
3) Rear-center audience
4) Rear-corner audience

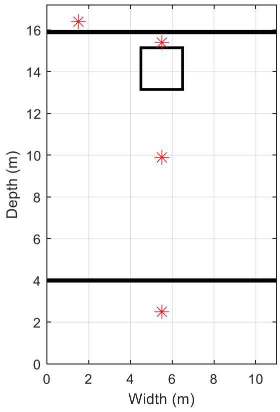

Figure 3.1 Sound monitoring locations (red asterisks) in the venue where the front 4 m is a raised stage, and the rear 1 m is folded seating. The small square indicates the mix position.

The positions were chosen to reflect easily accessible areas for the installation of meters as well as locations that could provide the best possible data to relate to sound exposure throughout the venue. The center audience position complies with the WHO standard, when used with a correction to a reference position which is at audience head height [2].

While such an audience position is known to provide a good representation of audience sound exposure (with correction applied), it is unlikely to capture the sound exposure of musicians. This led to the inclusion of the center stage monitoring position. It would not only provide information on sound levels on stage but also would provide invaluable information on the impact of stage sound emanating into the audience area. This will be explored in detail in Section 3.5.

System A’s meters were mounted to the grid using zip ties (although screws could have been used, if the meters were to be installed on a more permanent basis), System B’s meters were mounted to the grid with the provided mounting hardware, and System C’s meters were suspended from the grid by their power cables (by design). All meters at each location were positioned within 20 cm of one another in each primary dimension. The meters for Systems B and C were provided with hard-wired power to avoid battery life issues. This option wasn’t available for System A.

3.4 Calibration procedure

While the 12 sound meters (four each from Systems A, B and C) installed in the venue were to collect data throughout the study, these alone couldn’t guarantee accurate tracking of sound exposure due to their relatively remote location to the occupied areas, remembering that the venue has a line array sound system which is directed away from the ceiling where the meters are located.

To overcome this issue, a grid of 40 measurement points was laid out across one half of the venue (assuming venue symmetry), where 12 points were on the stage and the remaining 28 points were in the audience (Figure 3.2). The grid points were spaced at 1.5 m in both horizontal directions. The measurements were taken at floor/stage level to avoid comb filtering due to the floor/stage reflection. An additional measurement point was included at the mix position (FOH). This is to reflect that it would be the mix position where the necessary spot measurements would be taken during performances, hence the need for a calibration measurement here.

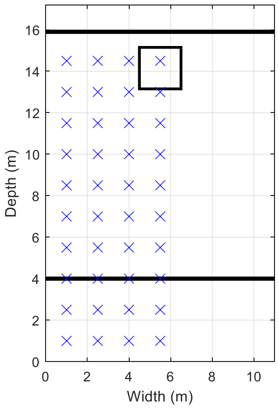

Figure 3.2 Measurement point locations (blue crosses) in the venue. The mix position measurement point is excluded from this plot.

Calibration was carried out using a Bruel & Kjaer 2245 Class 1 sound level meter (SLM) set up to measure L_{Aeq}, L_{Ceq} and 1/3 octave band data (identical to the metrics logged by System C). The calibration procedure in the unoccupied venue was as follows (assuming that the venue was set up for a standing audience, the three sound monitoring systems were active and logging data, and the SLM was calibrated):

- Use the SLM to measure the ambient noise level (dBA) at the mix position with the sound system muted.
- Turn on the venue sound system (using the house default settings). Run pink noise through the system, increasing the level until the SLM records a noise level of at least 40 dBA above the recorded ambient noise level of the venue at the mix position.
- With the pink noise playing through the sound system, take 30-second pink noise measurements at each of the 40 measurement points with the SLM. Take an additional measurement at the mix position.

After downloading the data from the SLM and Systems A, B, and C, correction values could be calculated to provide mapping between each of the four sound monitoring locations in the ceiling to the measurement grid points, using Equation 3.1.

$$k_{cal}\left(i,j\right)=L_{eq,cal}\left(i\right)-L_{eq,cal}\left(j\right) \qquad (3.1)$$

where the correction value between the ith measurement grid location and the jth ceiling monitor location, $k_{cal,i,j}$, is calculated by subtracting the calibration measurements (L_{Aeq}, L_{Ceq}, 1/3 octave) from Systems A, B, and C from the corresponding SLM measurements. Although a single value correction approach is known to oversimplify the relationship between the two points once an audience enters a venue (due to frequency dependent absorption), this approach has been used in this work to simplify development of the analysis procedure, although frequency-dependent correction was also calculated, which will be implemented within the analysis procedure as part of future research. Both methods are outlined in the WHO standard, with the frequency-dependent method being preferred [2].

Correction values were calculated for the L_{Aeq}, L_{Ceq} and 1/3 octave band data. A pair of plots are given in Figure 3.3 as examples of the correction values obtained after following this calibration procedure.

On the day of a performance, further calibration is required, principally to capture any sound system setting changes prior to the start of the show. The procedure required that after sound check, but before the venue was open to the public, pink noise be run through the system at the show level and a 30-second pink noise measurement taken with the SLM at the mix position.

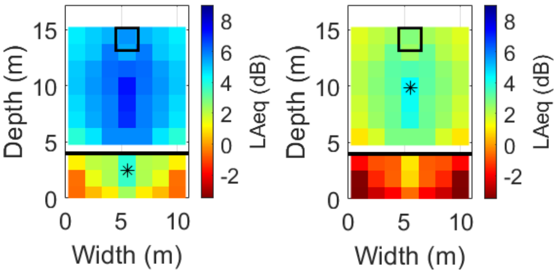

Figure 3.3 Example L_{Aeq} (dB) correction values (System C) for the center stage location (left) and center audience location (right)

Finally, measurements during the performance are required. The procedure stipulated that a 30-second measurement with the SLM was to be carried out every 30 minutes at the mix position. These measurements would capture the overall sound and spectral levels for each band which, critically, contain contributions from the sound system and the stage.

Prior to these show-time measurements, only the sound system output has been captured. In a small venue such as this, it should be expected that the sound level coming off the stage (due to instruments and monitor wedges) will significantly impact the audience and (of course) the musicians on stage [1,2,15]. With spot measurements throughout the performance, it was possible to isolate the sound system and stage contributions across the venue.

3.5 Analysis procedure

The aim for the analysis procedure was to estimate sound level, and corresponding noise dose, throughout the venue, from a relatively small number of fixed monitoring locations, while isolating contributions from the sound system and stage sound. Due to the unknowns during the calibration procedure set out in Section 3.4, principally regarding the sound emissions from the stage area, this was challenging and not without issue. Nonetheless, an analysis procedure was developed using the available data and is outlined here, where limitations of the procedure are highlighted, as necessary.

Two pre-show metrics must be calculated based on the mix position measurement immediately following sound check. As the mix position (FOH) is the only measurement grid location that was monitored after the calibration of the system, a pre-show correction value (k_{pre}) is obtained with Equation 3.2.

$$k_{pre}\left(FOH,j\right)=L_{eq,pre}\left(FOH\right)-L_{eq,pre}\left(j\right) \qquad (3.2)$$

Additionally, a set of gain factors relating the four monitoring locations to one another, with the center stage location (j = 1) used as the reference, can be determined with Equation 3.3.

$$GF_{pre}\left(j\right) = L_{eq,pre}\left(j\right) - L_{eq,pre}\left(1\right) \tag{3.3}$$

Next, a set of weighting factors must be computed to determine the relative influence of each monitoring location on each point in the measurement grid spanning the venue. This is carried out through a geometric evaluation of the locations considered, where closer proximity naturally will lead to a higher influence on the estimated level.

Once distances were calculated between each monitoring location and each measurement grid point, these were converted to weighting factors (Equation 3.4) and normalized so that the set of weighting factors for each measurement grid point sum to one (Equation 3.5). The weighting function was chosen through experimentation with early datasets, where it was found that weighting performed best with increased favor to “local” monitoring locations.

$$w_{raw}\left(i,j\right) = 1\big/d_{i,j}^{4} \tag{3.4}$$

$$w_{norm}\left(i,j\right) = w_{raw}\left(i,j\right)\Big/\sum w_{raw}\left(i\right) \tag{3.5}$$

where the normalized weighting for the jth monitoring location at the ith measurement grid point, $w_{raw}(i,j)$, is calculated by dividing the raw weighting for the jth monitoring location at the ith point, $w_{raw}(i,j)$, by the sum of all raw weights for the ith point. The raw weighting is based on the distance between the jth monitoring location and the ith point.

It must be noted that the chosen weighting function is likely to introduce certain errors into the sound level estimations, as the venue in question is indoors, meaning that such a simple relationship is unlikely to be observed across the venue (especially near reflecting surfaces). Further research is necessary to determine if any errors introduced through this process are acceptable or if there is a more robust function that can be implemented.

Next the analysis considers the data collected during the performance. First the gain factors between the monitoring locations are calculated with Equation 3.6, which follows the same process as Equation 3.3.

$$GF_{event}\left(j\right) = L_{eq,event}\left(j\right) - L_{eq,event}\left(1\right) \tag{3.6}$$

The difference between the gain factors pre-show and during the event is that during the event the monitoring locations will receive sound energy from the stage and the sound system, while the pre-show data will only contain energy from the sound system. The overall gain is also calculated by comparing the recorded levels during the event and pre-show (Equation 3.7).

$$G_{event}\left(j\right) = L_{eq,event}\left(j\right) - L_{eq,pre}\left(j\right) \tag{3.7}$$

The gain factors at the monitoring locations can be calculated for only the sound energy from the stage, following the noted difference between the pre-show and event gain factors (Equation 3.8).

$$GF_{stage}\left(j\right) = GF_{event}\left(j\right) - GF_{pre}\left(j\right) \tag{3.8}$$

This step in the analysis procedure requires further research, as it makes a crucial approximation. All the system calibration data is based on the measured sound propagation for the sound system. In this and later processes for resolving the stage contributions to the overall sound level, the sound system’s propagation characteristics are applied, due to lack of knowledge regarding the propagation characteristics of the various sound sources on the stage (which are likely to change from act to act).

The sound system gain between the pre-show and performance itself can now be calculated by summing the calculated mean overall gain from all monitoring locations except the stage location and the mean gain factors due to the stage sound, again excluding the stage monitor location (Equation 3.9). This process is a summation rather than a subtraction as all gain factors will be negative, hence this will subtract the influence of stage sound from the overall gain to isolate the sound system.

$$G_{event,PA} = \overline{G_{event,aud} + GF_{stage,aud}} \tag{3.9}$$

From this, the SPL at the mix position (FOH) due to stage sound only can be calculated (Equation 3.10) from the SLM spot measurement during the show (or mean if there are multiple spot measurements taken during a single act), the sound system gain as calculated in Equation 3.9, and the pre-show spot measurement. If this results in a value less than or equal to zero (indicating that the contribution from stage sound was greater than that from the sound system, which is unlikely but possible), then this value must be set to the ambient noise level, as measured during the calibration procedure.

$$L_{eq,stage}\left(FOH\right)=20\log_{10}\left(10^{L_{eq,event}\left(FOH\right)/20}-10^{\left(L_{eq,pre}+G_{event,PA}\right)/20}\right) \tag{3.10}$$

A similar calculation can be carried out to determine the SPL at the mix position (FOH) due to the sound system only (Equation 3.11).

$$L_{eq,PA}\left(FOH\right)=20\log_{10}\left(10^{L_{eq,event}/20}-10^{L_{eq,stage}\left(FOH\right)/20}\right) \tag{3.11}$$

From this, the sound level due to the sound system in isolation can be calculated for each measurement grid point (Equation 3.12) using the FOH level calculated with Equation 3.11, the earlier calculated correction values from the calibration (k_{cal}) and pre-show (k_{pre}), and the set of normalized weights calculated in Equation 3.5.

$$L_{eq,PA}\left(i\right)=w_{norm}\left(i\right)\left[L_{eq,PA}\left(FOH\right)-k_{pre}+k_{cal}\left(i\right)\right] \tag{3.12}$$

Using this value, the sound level due to stage sound only can be calculated in Equation 3.13, remembering again to replace any value less than or equal to zero with the ambient noise level during calibration.

$$L_{eq,stage}\left(i\right)=w_{norm}\left(i\right)\left[k_{cal}\left(i\right)+20\log_{10}\left(10^{L_{eq,event}/20}-10^{\left(L_{eq,pre}+G_{event,PA}\right)/20}\right)\right] \tag{3.13}$$

The sound levels calculated for each measurement point due to each monitoring location can be summed to obtain a single level for each of the measurement grid points using Equations 3.14 and 3.15.

$$L_{eq,PA}\left(i\right)=\sum L_{eq,PA}\left(i,j\right) \tag{3.14}$$

$$L_{eq,stage}\left(i\right)=\sum L_{eq,stage}\left(i,j\right) \tag{3.15}$$

Lastly, the total sound level can be calculated for each measurement grid point using Equation 3.16.

$$L_{eq,total}\left(i\right)=20\log_{10}\left(10^{L_{eq,PA}\left(i\right)/20}+10^{L_{eq,stage}\left(i\right)/20}\right) \tag{3.16}$$

Should an estimate of the noise dose (D) across the venue be required, this can be calculated using Equation 3.17, in line with guidance from the WHO standard [2]. Note that this calculation is based on occupational guidance from the UK, where an upper limit of 85 dB $L_{Aeq,8hrs}$ is allowed, and assumes that anyone present has had no significant exposure at any other point during the day (an assumption that may not always be true, especially for the musicians and staff members who were present during sound check).

$$D=\frac{100}{8}T_{event}\left(2^{\left(L_{eq,total}-85\right)/3}\right) \tag{3.17}$$

It is worth noting that the described analysis procedure doesn't require all four monitoring locations to be used. At minimum, two monitoring locations must be inspected, one above the stage and one above the audience. This will be explored in the results, as a system consisting of two monitors will be more practical than one consisting of four.

4 Results and analysis

Due to time limitations on the venue and staff availability, only one full performance (spanning four bands) was monitored. This, nonetheless, assisted in early validation of the sound level monitoring and analysis procedure described in Section 3.

Upon initial analysis of the data, it was found that System A's measurements were 5-10 dB higher than those of Systems B and C, which can be attributed to System A being uncalibrated.

Initial inspection of the data from Systems B and C indicated that these systems produced measurements within 0.5 dB of one another for the duration of the measurement period (Figure 4.1). Any differences are within the margin of error that could be expected due to differences in the location of each system's meters. As System C provided both L_{eq} and spectral data, it was used for the remainder of the data analysis presented in this paper.

First, the mix position SLM measurements from the four bands' performances can be compared to the calibration and pre-show measurements (Figure 4.2 and Table 4.1). Remember that the band performances will have sound system and stage contributions, while the calibration and pre-show measurements are of the sound system only.

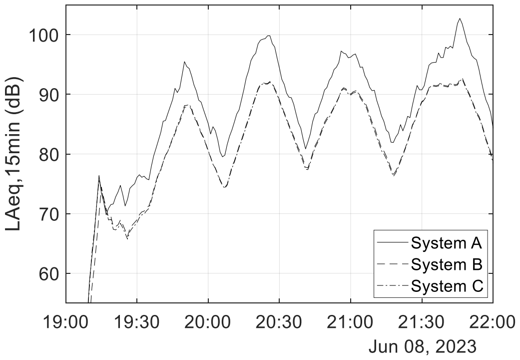

Figure 4.1 Comparison of measured $L_{Aeq,15min}$ data from all three monitoring systems (rear corner monitoring location data shown here). Note that Systems B and C's traces overlap one another.

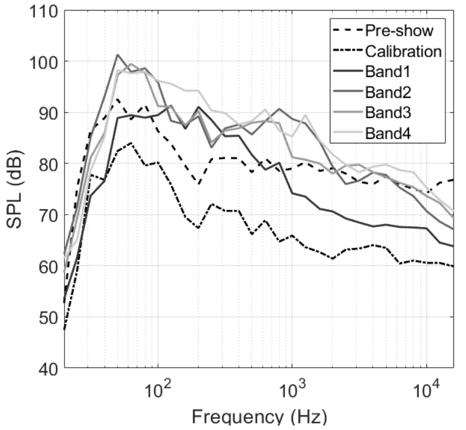

Figure 4.2 Mix position 30-second SLM magnitude response measurements for the calibration, pre-show and 4 bands' performances

Table 4.1 Mix position 30-second SLM sound level measurements for the calibration, pre-show and 4 bands' performances

Measurement	L_{Aeq} (dB)	L_{Ceq} (dB)
Calibration	76.8	88.4
Pre-show	90.3	97.8
Band 1	88.9	98.8
Band 2	96.6	105.6
Band 3	94.3	103.9
Band 4	97.1	105.5

Full sets of analyzed data are presented in Figures 4.3 through 4.6 on the following pages. Figure 4.3 shows the analysis with all four monitoring locations while Figure 4.5 uses only the center stage and center audience monitoring locations.

As can be seen in the data, aside from the first band, all other performances on their own exceeded the daily sound exposure allowance for those on the stage or close to it. This indicates that the stage levels are a significant factor for sound exposure, as highlighted in the WHO standard [2] and the AES technical document [1].

While only the center stage location indicates a noise dose approaching 1000% of the daily limit, remember that the analysis was based on the sound system's propagation characteristics, where a concentration of sound along the center line of the venue is expected due to the left/right configuration of all sound system elements, resulting in constructive interference at this location and varying comb-filtering effects off-center. It may be the case that the full stage area is receiving what is shown for center stage, although further research is necessary to confirm this.

While a more robust validation of the level estimates will be the focus of a future study where noise dosimeters can be deployed to volunteers, a preliminary validation can be carried out by comparing the sound level estimates at the nearest measurement grid point to the mix position (with SLM spot measurements throughout the performance).

While not a direct comparison (as the grid points are all based on ground plane measurements and the mix position measurement was at a height of 2.1 m), the data should provide a relatively close match. The estimates are likely to be slightly higher than the mix position measurements, because of audience absorption. Additional errors are due to the time the SLM measurements were made, remembering that these 30-second measurements were taken every 30 minutes, while the monitors were continuously recording throughout the performance. It may have been that a particular 30-second measurement captured a point in the performance when a band was unusually quiet or loud, hence skewing the sound exposure estimation. Future research should investigate continuous monitoring at the mix location to avoid this source of error. The outcomes from the data analysis are presented in Tables 4.2 and 4.3.

The differences between the mix position L_{Aeq} and the nearest grid point L_{Aeq} estimate aren't insignificant. A sound exposure difference of even a few decibels can determine whether someone exceeds their daily noise dose or not. For example, if the data were adjusted to simulate either the sound system and stage being attenuated by 3, 6 or 9 dB (or attendees wearing 3, 6, or 9-dB hearing protection), the effect on the estimated noise dose is profound (Table 4.4).

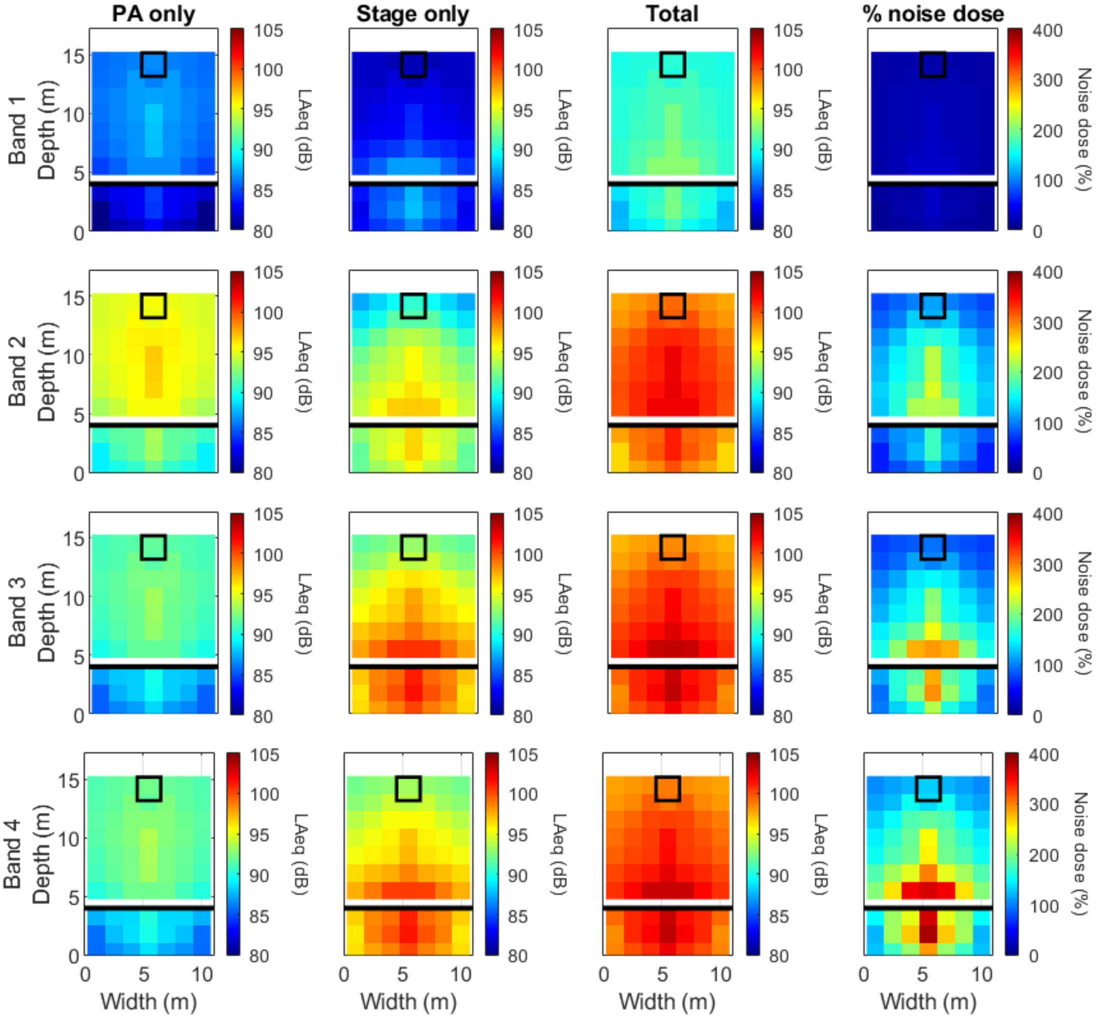

Figure 4.3 Sound level data across the entire performance (System C, all 4 monitors). Each band's set is shown in a separate row. The four columns show sound levels (dB L_{Aeq}) due to the sound system only, stage sound only, total sound level, and estimated noise dose.

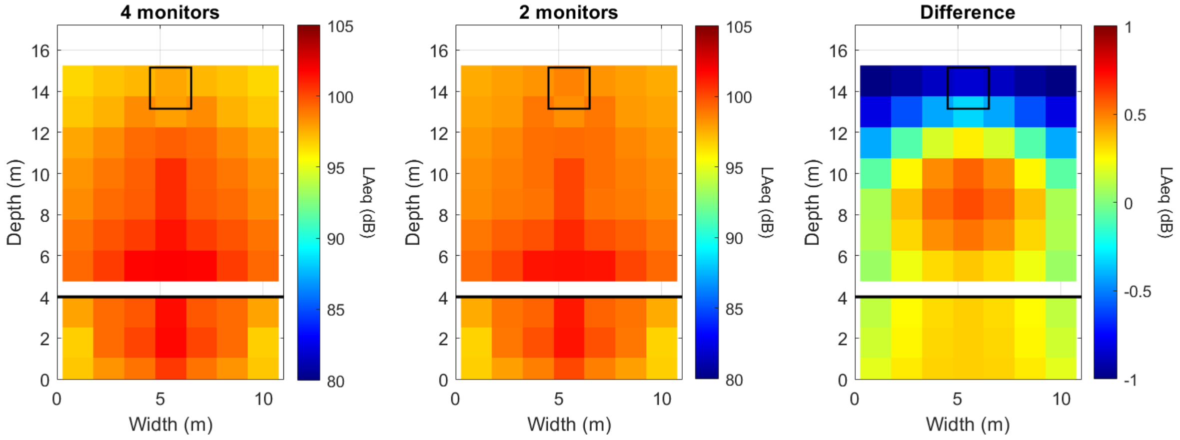

Figure 4.4 Estimated sound levels (dB L_{Aeq}) across the venue for the entire performance using all 4 monitors (left) and only 2 monitors – the center stage and center audience monitors (center) and the difference between the 4-monitor and 2-monitor analyses (right)

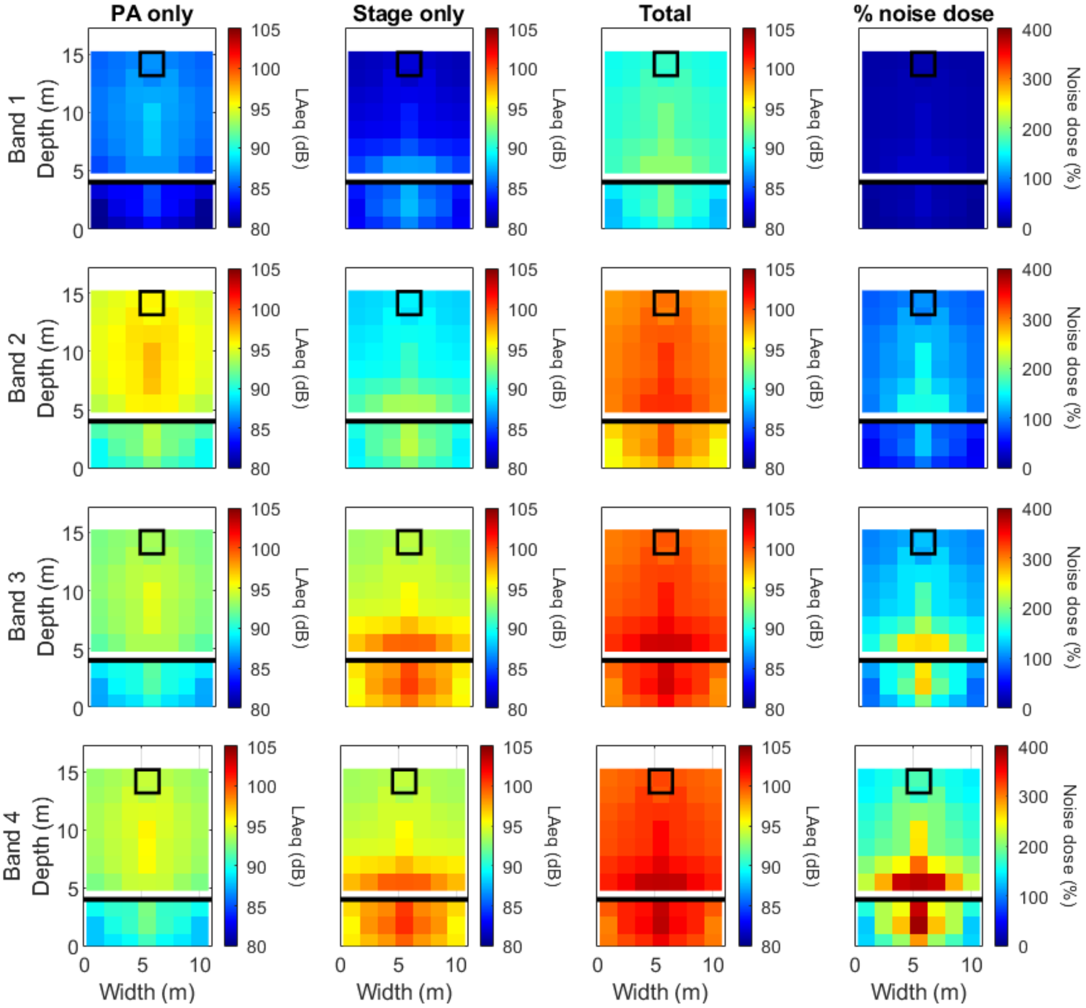

Figure 4.5 Sound level data across the entire performance (System C, 2 monitors). Each band's set is shown in a separate row. The four columns show sound levels (dB L_{Aeq}) due to the sound system only, stage sound only, total sound level, and estimated noise dose.

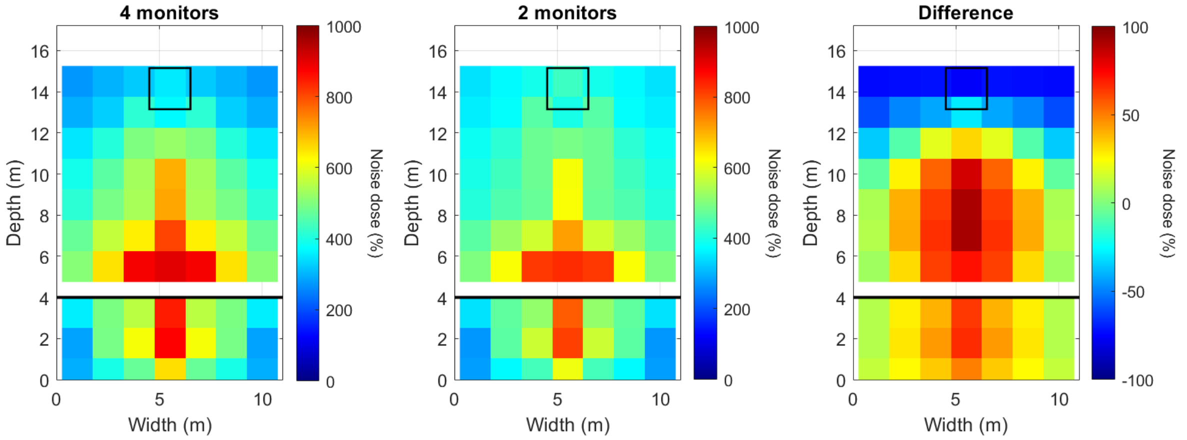

Figure 4.6 Estimated noise dose across the venue for the entire performance using all 4 monitors (left), only 2 monitors – the center stage and center audience monitors (center) and the difference between the 4-monitor and 2-monitor analyses (right)

Table 4.2 Comparison of mix position SLM measurements and the nearest ground plane grid point estimates for each band during the event (System C, all 4 monitors)

Band	FOH SLM (dBA)	Meas. grid estimate (dBA)	Diff (dBA)
1	88.9	89.9	1.0
2	96.6	97.7	1.1
3	94.3	97.4	3.1
4	97.1	97.8	0.7

Table 4.3 Comparison of mix position SLM measurements and the nearest ground plane grid point estimates for each band during the event (System C, using 2 monitors)

Band	FOH SLM (dBA)	Meas. grid estimate (dBA)	Diff (dBA)
1	88.9	89.7	0.8
2	96.6	98.0	1.4
3	94.3	98.8	4.5
4	97.1	99.2	2.1

Table 4.4 Estimated minimum, mean and maximum noise dose (D) for different levels of attenuation (sound system level reduction or hearing protection)

Attenuation (dB)	D (min)	D (mean)	D (max)
0	270%	511%	901%
3	135%	255%	451%
6	67%	128%	225%
9	34%	64%	113%

This shows that even a moderate amount of sound exposure reduction can bring most venue occupants within safe listening levels.

5 Conclusions and further work

Sound level monitoring at live events has become commonplace (at least in Europe) over the past decade. This trend is likely to spread across the world, due to efforts by the WHO and AES to educate the public and key stakeholders at live events on the importance of safe listening (and practical methods for achieving this).

Sound exposure monitoring, however, is generally absent at live events due to the significant costs associated with this activity (recruiting volunteers, obtaining noise dosimeters, conducting the data analysis, etc.). This pilot study provides a possible method for estimating noise dose not just for audience members, but for all occupants of a performance space in a music venue. This can be achieved with as few as two relatively low-cost sound level monitors suspended above the audience and stage, respectively, and a one-time calibration procedure which takes no more than one hour to complete. A few well-placed spot measurements during each performance complete the required dataset for the estimation of noise dose for all areas of a venue.

There are several unresolved issues that have been highlighted throughout this paper, most stemming from the sparse nature of the collected data. While many of these would be resolved by extending the spot measurements to audience and stage locations during a performance, this is impractical, especially for small venues where there may only be one crew member responsible for the sound system. A preference, therefore, must be for practicality and ease of use. Refinement of the data analysis procedure is required to improve the accuracy of the noise dose estimates (ideally to within 1 dB of the actual dose). This will require further research over a longer period than this pilot study allowed.

Overall, the process of revealing such sound exposure data from commonly collected live event data should be seen as something that opens the door to improved working practices at live events but shouldn’t be seen as a method to police live events with the aim of shutting down offenders. This would inevitably disadvantage small venues and would result in a reluctance to embrace such enhanced data analysis methods.

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