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Characteristics of personal sound and noise exposure at music festivals and events

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ABSTRACT

Regulations regarding sound exposure at music festivals and events are aimed to protect the audience's hearing. Although guidelines and laws exist for most countries and globally (World Health Organization, WHO), monitoring and controlling the sound levels is mostly based on data from a single representative measurement point within the audience. Insight into the personal sound exposure characteristics of people attending music events is scarce but can provide a unique insight into how representative the current sound level measurements are in relation to personal sound exposure. This approach requires personal dosimetry of attendees, and this study presents and analyses personal exposure data from 42 participants (19 females) between 18-25 years old, who attended one out of six large-scale music events, organized in Belgium and the Netherlands. Individual exposure was measured by clip-on noise dosimeters secured to the shoulder of participants. Both A and C-weighted sound level characteristics (broad and narrow band) were analyzed over the entire exposure period (between 7 and 22 hrs). Individual exposures were compared to the local regulations and the WHO guidelines. Levels presented to the participants at four out of six events exceeded the WHO recommendation ($L_{A,eq}$ = 100dB). The equivalent exposures ranges were [85.2,104.5] dBA and [97.1,119.6] dBC, for $L_{A,eq}$ and $L_{C,eq}$ respectively. Furthermore, the $L_{C,peak}$ and $L_{AF,max}$ fluctuated between [133.6,143.5] dBC and [110.6,142.3] dBA respectively. These results indicate that the personal exposure, considering the silence or low-exposure periods during such events, was very close to the safe-listening limit of the WHO or local legislation, but that individual differences in peak exposure exist.

Keywords (3-6): music event, festival, individual noise exposure, dosimetry

INTRODUCTION

During large-scale music events or festivals, the audience is exposed to a wide range of sounds and noise. Additionally, sound exposure levels have been found to vary strongly between participants **[1]**, which implies that caution and control of the emitted sound levels is advised along with an effort to promote wearing hearing protection. Exposure to excessive sound levels for longer durations can cause damage to the auditory system. Temporal or permanent threshold shifts of the listener's hearing may hence occur, causing undesired lasting effects, including tinnitus, hyperacusis, dullness, etc. **[1,2,3,4].** Partly based on the large number of people attending these type of amplified music events, an elevated risk for hearing damage exists for a significant part of the younger population (1.1 billion as estimated in 2015 by WHO) **[5].** To avoid harmful sound exposures, guidelines and regulations are enforced for music events within multiple countries. In Europe, these include for example France, Belgium, the Netherlands, Norway, and globally the World Health Organization proposed safe listening limits. The measurements and regulations in question mostly consider the upper limits on sound exposure as recorded at the Front of House (FOH) and expressed in sound pressure level (SPL) as defined in **NEN-EN-ISO 9612:2009 en.** Weighting is often applied to the different frequency bands contributing to the resulting SPL in an A-weighted (L_A) sound pressure level to better mimic human perception, as human hearing is less sensitive below 250Hz (**ISO 226:2003)**. The C-weighting also considers lower frequencies down to 50Hz and hence includes bass content of the music. Lastly, the regulations distinguish between instantaneous measurements, more directed towards the sound peaks during sound exposure ($L_{C,peak}$ and $L_{AF,max}$), or time-averaged values spanning the full exposure duration ($L_{A,eq}$, $L_{C,eq}$) or shorter intervals ($L_{A,eq,15min}$, $L_{A,eq,1min}$). A descriptive overview of a few regulations within Europe is present in **Table 1.**

The regulations are a powerful tool in preventing hearing damage at music events but are typically monitored by a single calibrated microphoned positioned at the FOH. As the FOH is located behind part of the audience, levels presented to the listener can be louder and strongly depend on listeners' location within the venue itself **[4]**. A clear insight into the experienced levels cannot directly be derived from the regulatory monitoring measurements and crucial information is thus lacking regarding the levels individuals receive during this type of music events. Studies on the individual sound exposure are scarce **[1],** and this paper thus aims to bridge this gap between event exposure data and the individual dosimetry. Specifically, the study evaluates individual and mean exposure characteristics and relates these to present regulations and guidelines measured at the front of house.

*As the evaluated events in question took place in either the Netherlands or Belgium, regulations from both countries will be taken as baseline, see **Table 1**. Additionally,* $L_{A,eq}$ *regulations from the WHO and peak regulations from the WHO and Germany will be considered as well to reflect a more generalized guideline. The latter allowing consideration of peak exposure as well which is not included in Belgian and Dutch regulation. Both individual subjects, per event and global behaviors were evaluated.*

An initial overview will be given of the observed spread in behavior between different participants as to their dynamic ranges and averaged exposure. Afterwards the level variance over all participants and between events is considered both in 15-minute intervals and full exposures with consideration for low frequency content. Lastly, exposure duration per event day will be evaluated along with supra-threshold exposure in terms of guidelines from Belgium, the Netherlands, and Germany. Afterward, concluding remarks are given on the observed individual exposure and their dynamic ranges.

Country	
Belgium	$L_{A,eq,15min}$ =102dBA, $L_{A,eq,60min}$ =100dBA **[7]**
The Netherlands	$L_{A,eq,15min}$ = *103dBA* **[8]**
Germany	$L_{A,eq,30min}$ = 99dBA, $L_{C,peak}$ = 135dBC **[9]**
WHO	$L_{A,eq,15min}$ = 100dB [10], $L_{AF,max}$ = 110dB **[11]**(older)
France	$L_{A,eq,15min}$ =102dB $L_{C,eq,15min}$ =118dB **[12]**
Norway	$L_{A,eq,30\,min}$ = 99 dB and $L_{C,peak}$ = 130 dB **[13]**

Table1: Guidelines and regulations for sound and noise exposure at events

MATERIALS AND METHODS

Exposure dosimetry data was recorded on 6 large scale musical events, taking place either in Belgium or the Netherlands during the spring and summer of 2022.

A cohort of 42 participants (19 females) between 18-25 years was examined for this study. Pre-event hearing thresholds were determined for each participant by tympanometry and conventional audiometry. Normal hearing was identified for each subject, limiting bias due to impairment of present hearing loss or damage.

The personal noise exposure of each participant was recorded using Casella dBadge2 **[14]** noise dosimeters with a **1/2″ diameter microphone** covered by a foam windscreen and attached to each test subject. The dosimeters were secured via clips to either clothing or bags as worn by the participants. Devices were mounted on shoulder height as close to the ear as possible, to capture ear exposure as good as possible. The recording device provided both global exposure markers ($L_{A,eq}$, $L_{C,eq}$) **ISO 9612** over the entire exposure duration as well as in 1-second and 1-minute intervals. Besides this, an A-weighted sound level measured with Fast Time Weighting ($L_{AF,max}$) and the peak C-weighted sound level ($L_{C,peak}$) were recorded (ISO 9612**),** to better capture peak exposures as well. Recordings spanned the full exposure at the event and were activated upon arrival at the event and lasted until participants left. The minimal exposure duration **was 4.4 hours** and, individual exposure of four participants consisted of two-day recordings at the event. The values over the two days were recalculated to single day exposures, i.e. individual exposure per event per day. Time averaged values of both days were thus combined through time weighted energy-based averages with respective exposure duration. Maximal values of peak exposures of both days were only kept and regulation exceedance counts were averaged across both days.

Individual ear protection and worn time were registered for optional future compensation of recorded levels but are not considered in the conducted analysis. Given recent findings on the limited wear of earplugs by the listening audience at events (less than 25%) **[15]** in the Netherlands, the recorded levels are assumed to be presented to the surrounding audience at the listener position unattenuated. The measurements thus also provide an accurate representation of the levels the audience experienced.

Regular checkups of the active recording and correct mounting were carried out during the measurements at each event. It should however be stated that heavy rainfall occurred during one of the events (6 participants**,** F3). Thin plastic bags were loosely mounted around the microphone foam as protection. A mainly high frequency attenuation can hence be expected to occur **[16]** for the recording at F3. As the plastic bag thickness was assessed to be minimal (0.03mm) a potential 5 dB attenuation was considered in the highest frequency bands of the dosimeters (4kHz, 8kHz). Recalculation of the $L_{A,eq}$ and $L_{Z,eq}$ for these subjects, considering a potential high frequency attenuation, resulted in a respective maximal underestimation of exposure by 1.7 dB and 0.2 dB, respectively. A minimal influence can be expected for $L_{C,peak}$

measurements as well, but for $L_{A,eq}$ the cover influence is expected to cause notable changes in exposure. As these measurements contained the lowest levels, being likely also a consequence of the rainfall, an overestimation of the lower limit on the observed dynamic range is expected over all subjects and will be taken into account. Furthermore, participant behavior was influenced drastically by partial close-off of the musical performance venues on the event due to crowdedness inside them during the rainfall. Hence, shelter was taken during large periods of the event far away from the musical performances.

Besides the F3 measurement, it should also be stated that $L_{C,peak}$ values as recorded with the dosimeters saturated at 143dB. Maximal peak values above 143dB were thus not captured by the dosimeters and can lead to a potential underestimation of the peak exposure in this study.

Both the hearing screening and data collection of each participant pre- and post-event, as well as dosimetry data capture during the event were acquired and carried out by N. De Poortere as part of a separate study on the influence of sound exposure on hearing damage involving temporal and permanent threshold shifts [17].

RESULTS

Subject specific variability

Figure 1 shows the individual exposure frequencies of four participants to their respective A-weighted equivalent sound pressure level per 15-minute ($L_{A,eq,15min}$) intervals. The red colors indicate exceedance of the WHO limit at 100dBA and the binsize was 1dBA.

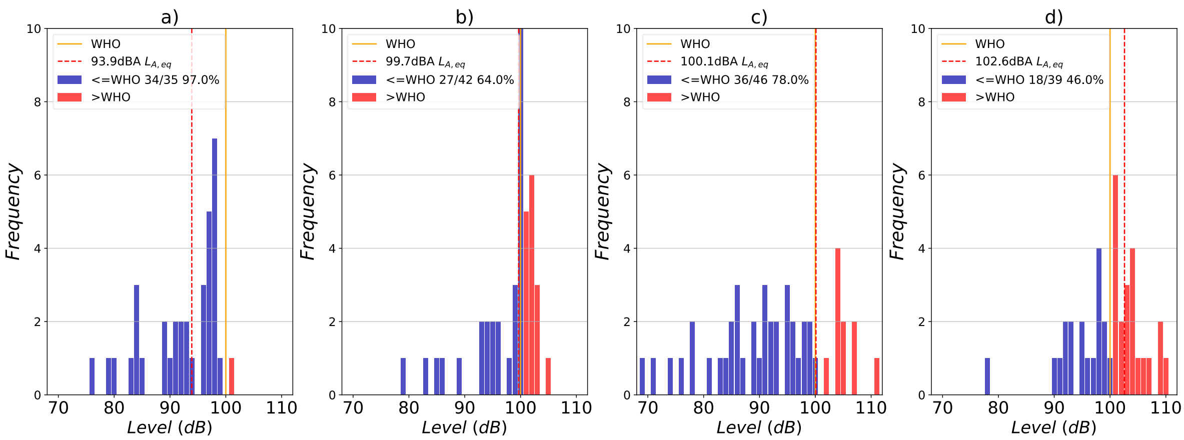

Figure 1: Illustration of the 15-minute $L_{A,eq,15min}$ (dB re. 20µPa) equivalent sound pressure exposure of four subjects as recorded during the full exposure duration together with WHO guideline (WHO15) of 100dBA in 1dBA bins.

The equivalent exposures over the entire duration are indicated in the label and show strong individual differences between exposure levels ($\boldsymbol{L_{A,eq,15min}}$) for similar $\boldsymbol{L_{A,eq}}$ values across the event (e.g., compare panels b and c). The individual dynamic range, lowest to highest experienced level for a single subject, varied within [24.8,41.60] dBA across participants, and across all subjects between [12.13, 41.60] dBA. The range of $L_{A,eq,15min}$ levels experienced by all participants on the different events spanned [68.99,114.97] dBA. For close to all subjects (excluding three) the WHO guideline of 100dBA was exceeded at least once over the entire exposure.

Global exposure

Besides the individual exposure, a broader view can be adopted given either per event or in general across them for all participants.

Figure 2 gives an overview of the full distribution of 15-minute intervals amassed from all participants (a) as well as the distribution of equivalent exposures $L_{A,eq}$ over the full exposure duration (b, 1dBA binsize). Boxplots of $L_{A,eq}$ and $L_{C,eq}$ are illustrated per event in (c) along with the WHO guideline with a separate focus on low frequency content(d).

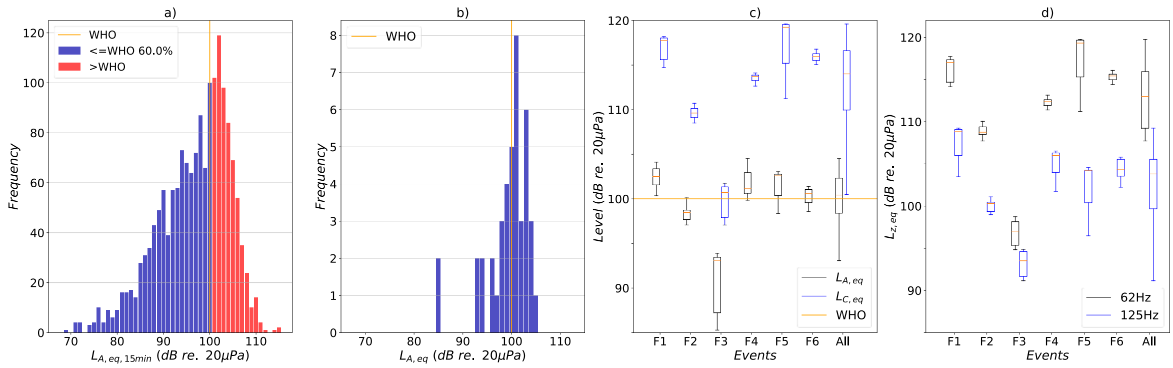

Figure 2: Histogram of the sound exposure across participants, expressed per 15-minute exposure intervals (a, 1dBA binsize) and equivalent exposure over the entire interval (b, 1dBA binsize). Distribution of the equivalent sound pressure levels per event both with A and C weighted (c) and low frequency content (d).

The distribution for 15-minute intervals for $L_{A,eq,15min}$ illustrates the earlier described spread in exposure [69.0, 115.0] dBA. **Figure 2a** indicates that across the entire time spent at all events 40% of their time was spent in levels above the WHO guideline of 100dBA. Expanding the 15-minute guideline to each full exposure duration **(Figure 2b, Table 3),** 57% of the attendees experienced an $L_{A,eq}$ above 100dB. Additionally, considering **Table 2,** the percentile levels **(L10, L50, L90)** are shown with the levels (dBA) above which 10, 50 or 90 % of the total recorded duration were spent respectively. **Table 3** presents the same percentile information, expressed in full exposure $L_{A,eq}$ per subject. Assuming a normal distribution for both $L_{A,eq}$ and $L_{A,eq,15min}$ their respective distribution parameters can be obtained **(Table 4).**

Event	# 15m intervals	>100dBA (WHO)	>102 dBA (B)	>103 dBA (NL)	L10 [dBA]	L50 [dBA]	L90 [dBA]
All	1660	665(40%)	450(27%)	348(21%)	105.2	97.9	86.2
1	490	280(57%)	217(44%)	178(36%)	106.2	101.1	89.6
2	189	63(33%)	26(14%)	9(5%)	102.4	95.6	87.1
3	169	1(1%)	0(0%)	0(0%)	97.6	88.7	76.4
4	166	89(54%)	61(37%)	37(22%)	103.7	100.3	94.6
5	289	113(39%)	74(26%)	61(21%)	105.6	97.4	86.2
6	357	119(33%)	72(20%)	63(18%)	104.9	95.9	85.3

Table 2: Statistical measures of individual and all event $L_{A,eq,15min}$ exposure intervals and respective surpassing counts of WHO, Belgian(B) and Dutch (NL) guidelines.

# subjects	>100dBA	L10 [dBA]	L50 [dBA]	L90 [dBA]
42	24(57%)	103	100.3	93.2

Table 3: Statistical measures from global $L_{A,eq}$ exposure.

Type	M [dBA]	SD [dBA]
$L_{A,eq,15min}$	96.6	7.6
$L_{A,eq}$	99.3	4.3

Table 4: Statistical distribution measures for $L_{A,eq}$ and $L_{A,eq,15min}$ across subjects

Table 5 presents an overview of the mean and standard deviation of both the $L_{A,eq}$, $L_{C,eq}$, $L_{Z,eq,62Hz}$ and the $L_{Z,eq,125Hz}$ to better illustrate the observed spread between the included events. An elevated $L_{C,eq}$ relative to $L_{A,eq}$ was observed for each event with a minimal difference, of at least 9.1dB. The $L_{A,eq}$ mean, non-energy based, per event exceeded the WHO 100dBA reference by maximally 2.4 dBA with values ranging between [90.7,102.4] dBA. Furthermore, when excluding F3 based on the present rainfall and limited exposure, mean $L_{A,eq}$ values ranged in [98.2,102.4] dBA. The mean $L_{C,eq}$ per event varied between [99.8,117.1] dBC. Regarding low frequency content levels for $L_{Z,eq,62Hz}$ ranged in [94.8,119.8] dB and at 125Hz in [91.2, 109.2] dB.

Event	$L_{A,eq}$ M [dBA]	$L_{A,eq}$ SD [dBA]	$L_{C,eq}$ M [dBA]	$L_{C,eq}$ SD [dBA]	$L_{Z,eq,62Hz}$ M [dBA]	$L_{Z,eq,62Hz}$ SD [dBA]	$L_{Z,eq,125Hz}$ M [dBA]	$L_{Z,eq,125Hz}$ SD [dBA]
All	99.3	4.3	112.6	6.1	102.2	4.8	111.6	6.9
1	102.4	1.3	116.9	1.4	107.4	2.4	116.1	1.5
2	98.2	1.2	109.6	0.7	100	0.7	108.9	0.7
3	90.7	3.8	99.8	2	93.2	1.6	96.8	1.6
4	101.8	1.6	113.5	0.5	105	1.7	112.3	0.6
5	101.1	2.7	117.1	3.6	102.1	3.5	117.2	3.7
6	100.3	0.9	116.3	1.3	104.3	1.3	115.7	1.4

Table 5: Statistical distribution equivalent exposure per event and globally

$L_{A,eq}$	Event	U	n1	n2	P	$L_{C,eq}$	U	n1	n2	P
	1	49	7	35	1.13E-02		28	7	35	6.35E-04
	2	59	7	35	3.13E-02		42	7	35	4.95E-03
	3	0	6	36	3.81E-07		0	6	36	3.81E-07
	4	70	7	35	7.91E-02		107	7	35	6.20E-01
	5	78	7	35	1.40E-01		69	7	35	7.32E-02
	6	135	8	34	9.87E-01		80	8	34	7.51E-02

Table 6: Mann Whitney U significance results

Table 6 illustrates the results of two-tailed Mann Whitney U tests as applied between individual events and the remaining group to evaluate significant difference of any group. As expected from the rainfall, a significant difference was found for $L_{A,eq}$ between event F3 (Mdn: 92.4dBA) and the other events combined (Mdn:101.0dBA) (U = 0, n1=6, n2=36, P<0.01), no other significant differences were observed ($\alpha = 0.01$) for $L_{A,eq}$. Significant differences ($\alpha = 0.01$) could also be identified for $L_{C,eq}$ between F1 (Mdn:117.0dBC) and the other events (Mdn:113.7dBC) (U = 28, n1=7, n2=35, P<0.01), between event F2 (Mdn:109.6dBC) and the other events (Mdn:114.1dBC) (U = 42, n1=7, n2=35, P<0.01) and between event F3 (Mdn:100.1dBC) and the other events (Mdn:114.1dBC) (U = 0, n1=6, n2=36, P<0.01).

Guidelines and regulations exceedance

Figure 3 presents an overview of the exceedance of both the German $L_{C,peak}$ (135dBC) guideline, the earlier used WHO guideline for $L_{AF,max}$ (110dBA) and the Belgian (102dBA), the Dutch (103dBA) and the WHO guideline for $L_{A,eq,15min}$ in relation to the equivalent exposure $L_{A,eq}$. Additionally, a linear fit is applied to the data and shown together with Pearson correlation coefficient both including and excluding F3, the former between brackets.

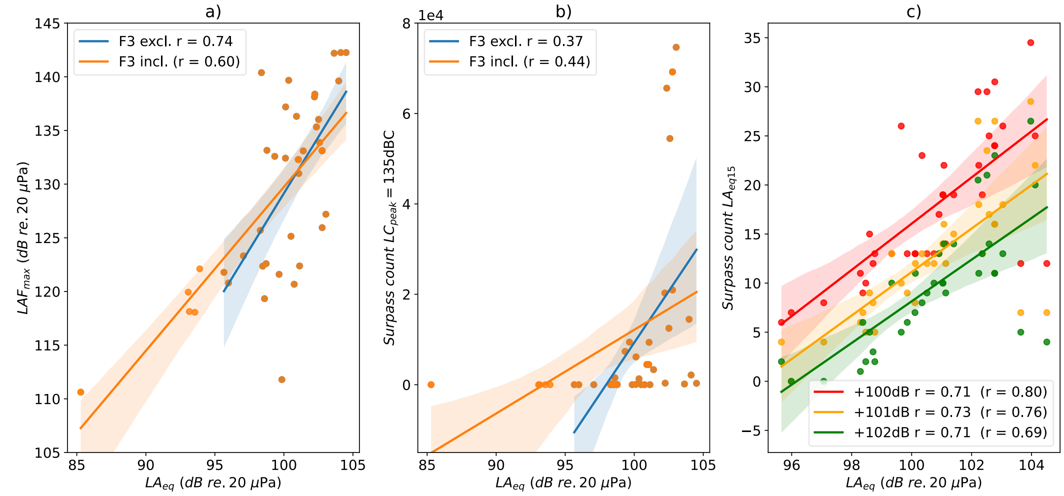

Figure 3: Individual exposure expressed in terms of the WHO guideline for $L_{AF,max}$ (a) and exceedance count of the German peak guideline ($L_{C,peak}$ = 135dBC) (b) and $L_{A,eq,15min}$ guideline (WHO, Belgian and Dutch) (c) as a function of the equivalent exposure level $L_{A,eq}$ per subject. F3 events are not illustrated in (c). Linear fits for the shown variables are shown with exclusion and inclusion of F3 between brackets.

For $L_{AF,max}$ a positive correlation (r = 0.60 incl. and r = 0.74 excl. F3) is observed between $L_{AF,max}$ and $L_{A,eq}$. The $L_{AF,max}$ spans a range of [110.6dBA, 142.3dBA] over all subjects. Relative to the 110dBA guideline as earlier imposed by the WHO [11], all participants were exposed to a fast-weighted A-weighted level above the reference WHO guideline with a mean exceedance of (*M* = 18.7dB, *SD* = 8.8dB).

For $L_{C,peak}$ the individual values per subject were not considered as potential skewing may bias data due to the limited dynamic range of the microphone. Only exceedance counts to their guideline values were considered. Alternatively, a skewed dynamic range was observed for $L_{C,peak}$, and ranged between [134.0,143.5] dBC. Exceedance count of $L_{C,peak}$ = 135dBC varied between [0, 75e3], note that these are instantaneous recorded occurrences**.** Additionally, **90.5%** of the participants experienced $L_{C,peak}$ values above the German guideline. Applying a linear fit, a limited correlation (r = 0.37 or r=0.44 if F3 is included) is present.

Correlation between $L_{A,eq}$ and the $L_{A,eq,15min}$ WHO, Belgian and Dutch guideline was assessed as well, (r = 0.71, 0.73, 0.71 respectively) excluding F3 and (r = 0.80, 0.76, 0.69 respectively) when including F3. Furthermore, the percentage of people experiencing at least a single exceedance amounted to **92.9%, 83.3% and 81.0%** of the participants for the 100, 102 and 103dB guidelines respectively.

Exposure duration and General exposure behavior

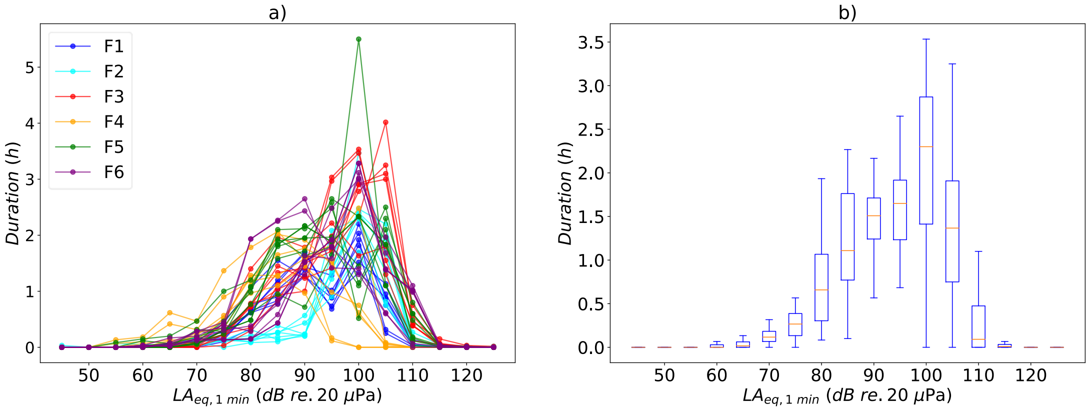

Figure 4: Exposure expressed by summed $L_{A,eq,1min}$ durations distributed in 5dB bins for individual participant per event (a) and the boxplot distribution per bin (b)

Event	All	1	2	3	4	5	6
M [h]	9.10	11.54	7.05	6.89	6.33	10.65	11.47
SD [h]	2.36	0.15	0.05	10.7	1.15	0.52	0.34

Table 7: Exposure duration per event

Figure 4 presents the individual exposure duration expressed as cumulative durations of 1-minute equivalent levels $L_{A,eq,1min}$ per 5dBA bin. Panel (a) illustrates the individual subject behavior color coded per event. Panel (b) gives the spread per 5dB band in duration.

The highest median and mean duration per 5dB band was situated around $L_{A,eq,1min}$ = **100dBA (+-2.5dBA)**. However, individual preference peaks varied between 85dBA and 105dBA. Additionally, a skewed exposure distribution is visible, with a faster drop-off above the peak than below it in most cases. Mean exposure durations for the four highest means occurred at 90dBA, 95dBA, 100dBA and 105dBA with a respective duration of 1.39h, 1.60h, 2.11h and 1.37h.

Table 7 presents the variation in exposure duration per event through mean and standard deviation. One day events exposure varied within [4.4, 11.8] hours with a mean duration of M = 9.10 hours and standard deviation of SD = 2.36 hours.

DISCUSSION

Individual exposure level variability

The present exposure as observed for subjects contained significant fluctuations both in overall level [69.0, 115.0] dB for 15-minute intervals of $L_{A,eq,15min}$ and also in dynamic range as experienced by each subject [12.1, 41.6] dBA. Furthermore, for similar equivalent exposures $L_{A,eq}$ as in case c, d (99.7dBA, 100.1dBA) for **Figure 1,** being close to the WHO guideline, limited information is communicated through $L_{A,eq}$ on the underlying observed dynamic ranges of both exposures (25.9dBA and 41.6dBA). Variation in level as present over smaller time-scales can hence not be captured by $L_{A,eq}$. This applies as well to guideline exceedances and the inter-subject variability of $L_{A,eq,15min}$. A higher level of exposure $L_{A,eq}$ may for example result in more exceedances of $L_{A,eq,15min,}$ however, it is not a necessity. Moreover, a sufficient reduction in variance can, even for elevated $L_{A,eq}$ exhibit a lower exceedance count. In **Figure 1** this is reflected by similar duration exposures (10.5 and 11.5 hours) attaining a 1.5-hour difference in time of guideline exceedance. The latter difference resulted in respectively 64% and 78% of the total duration being exposed to loud levels above the guideline. Larger deviating $L_{A,eq}$ levels can then as well emphasize these differences, as they are separated further from the guideline, ranging from a single exceedance occurrence to more than 50% of a 10-hour exposure duration spent at a level above the guideline. The equivalent exposure $L_{A,eq}$ over the full measurement period thus only provides a limited view of the entire spread in exposure levels. **Potential strong variations with more harmful elevated levels may thus be masked and compensated by low levels and can portray an, on average, acceptable level. The latter resulting in a misguiding view of the observed exposure.** Additionally, as most subjects passed the WHO guideline of 100dBA for a 15-minute interval at least once, variations clearly show the spread of levels that can be experienced despite a guideline-controlled level present at the Front of House as has been shown in another study as well **[6].**

Grand average exposure and exceedances

Across all students an equivalent exposure $L_{A,eq}$ of 99.3± 4.3 dBA was observed with ranges of [85.3,104.5] dBA. These levels are elevated both in variability and mean compared to other studies as conducted in Norway **[1]** (two events, $L_{A,eq}$ = 93.4 ± 1.0 dBA, with ranges [87.3,99.4] dBA and **92.6 ± 0.7 dBA** with ranges of [85.5,95.9] dBA) and Switzerland **[18]** (**$L_{A,eq}$ =95.1 ± 3.1 dBA**, with ranges of [87.3,103.8] dBA). However, rock concerts and other music events have been reported to observe similar levels around $L_{A,eq}$ = 100dBA **[19,20]** and should be expected solely based on the imposed guidelines. Across all events **90%** of the time was spent at levels above **86.2dBA**, 50% was spent at levels above 97.9dBA and 10% of the time was spent at levels above 105.2dB. Which are comparable to earlier found values at two music events **[1]** (L90 = 88.3dBA, L50 =96.7dBA, L10=103.8dBA).
The observed levels in **Figure 2a** indicate that across the entire time spent by event attendees, 40% of the time was spent in levels above the WHO guideline of 100dBA. A mean averaged exposure, across all subjects amounted to a daily 40.49Pa^2h, which is large compared to earlier suggested WHO limits **[16]** of $L_{A,eq,4h}$ = 100 dBA amounting to a 4-hour exposure of 16Pa^2h. However, considering day exposures lasted sometimes up to 12 hours **(Table 7),** three times the WHO guideline duration, they seem valid. Furthermore, elevated levels (up to 47Pa^2h) have been found for individuals at other music events as well **[1]**. Nevertheless, these exposures, although complying with guidelines and having observed mean values situated at guideline level do as well indicate caution to prolonged high level exposures.

Respective to the WHO, Belgian and Dutch guidelines (at 100dBA,102dBA and 103dBA), a total of **40%**, **27%, and 21%** of all $L_{A,eq,15min}$ measurements was spent at levels above those guidelines. Additionally, when considering equivalent exposure $L_{A,eq}$, ranging within **[85.3dBA, 104.5dBA],** 57% of the subjects was exposed to an average level above 100dBA. Furthermore, the reduced standard deviation of $L_{A,eq}$ with respect to $L_{A,eq,15min}$, from 7.6dBA to 4.3dBA, highlights the loss in representation potential of the variability in the full exposure.

Based on peak values for $L_{A,eq,15min}$ a preferred listening level is situated at 102dBA as most of the time was spent at this level (M = 2.1h), or for $L_{A,eq}$ a preferred level at 101dBA can likewise be concluded. Both the latter levels furthermore illustrate most of the time spent was located close to the WHO guideline indicating the individual behavior mirroring in guidelines. Additionally, mean $LA_{,eq}$ values per event **(Table 5)** also indicated exposure remained close to the country guidelines [102,103] dBA and the guidelines are as well reflected in the mean behavior of the subjects.

The individual levels per event in **Figure 2c and Table 5** illustrate the offset as present for each event between A and C weighted levels, giving a lower A-weighted value with a minimal difference in mean between A and C of at least 9.1dB. Hinting at the different spectral exposure as observed for each event. Additionally, as the mean differences in spectral content between 62Hz and 125Hz were not constant per event, the variation indicates spectral variability across events. Furthermore, for each event the low frequency exposure of the 62Hz band was more prominently present compared to 125Hz as is clear from the figures.

A significant difference for event F3 for both $L_{A,eq}$ and $L_{C,eq}$ (Mann Whitney U, P <0.01) was identified compared to the remaining events. This indicates the relevant influence the rainfall and associated measures had on observed exposure. Additionally, significant differences were observed for $L_{C,eq}$ in event F1 and F2, however, as no clear causes were identified and the limited consideration of $L_{C,eq}$ in this paper no data exclusion was considered.

Guideline exceedance in relation to $L_{A,eq}$

To show the relation of individual guidelines in relation to the global averages and to better show the distinct exposure properties, $L_{AF,max}$ and $L_{C,peak}$ and $L_{A,eq,15min}$ exceedance count of guideline values were considered. For each subject the $L_{AF,max}$ guideline of 110dB was surpassed, 90.5% of the subjects exceeded the $L_{C,peak}$ above 135dBC and the WHO $L_{A,eq,15min}$ = 100dB was exceeded by 92.9% of the participants.

A high correlation (r = 0.74, excl. F3) was observed between $L_{AF,max}$ and $L_{A,eq}$ and can be explained as higher maximal L_A values occurring more frequently at elevated levels. Nonetheless the relation is less pronounced for $L_{C,peak}$ exceedances of 135dBC (r = 0.37, excl. F3). The peak exceedances count shows a rather limited relation to $L_{A,eq}$ and thus presents an additional separate dimension of the exposure as experienced by the user not captured by solely time-weighted values and being complementary in content. This is best illustrated at elevated $L_{A,eq}$ levels for which exceedance count of $L_{C,peak}$ = 135dB still fluctuated strongly. Alternatively, for $L_{A,eq,15min}$ exceedances, the general correlation was higher than for $L_{C,peak}$ (r = 0.70, 0.73, 0.71 excl. F3) for 100dBA,102dBA and 103dBA exceedances. The $L_{A,eq,15min}$ exceedances can thus be limited and controlled to a better extend by $L_{A,eq}$ monitoring during an event. Nonetheless, a larger spread seems to be present at the elevated $L_{A,eq}$ levels indicating still the potential for complementary information between $L_{A,eq}$ and $L_{A,eq,15min}$.

Having said the above, the presented guideline comparisons and exceedances here are solely to illustrate the level of participants and potential harmful experiences. However, they do not serve as a direct indicator of event exceedances as these are user dependent. Nevertheless, they provide a valuable insight into the relation between guidelines and personal exposure and further add information on the experienced variability in exposures of the user. Additionally, the considered guidelines, being all surpassed in about 90% of the captured subjects, illustrate their implementation value beside the equivalent exposure $L_{A,eq}$ to quantify exposure.

Preferred level and exposure

Based on both the equivalent and 15-minute exposure ($L_{A,eq}$, $L_{A,eq,15min}$) and the durations shown in of $L_{A,eq,1min}$ (**Figure 4)** a clear peak in exposure can be observed at 100dBA of 2.1hours. The latter indicates a preference for this exposure level. However, compared to reported preferred listening levels around 83dBA **[21]**, the exposed 100dBA differs substantially. Being as the sound levels measured on a music event depends on a multitude of conditions (meteorological conditions, visitor count, and particularly the sound spectrum of the music amongst other) **[18]**, the observed levels do not necessarily reflect a preferred exposure level. Nevertheless, a clear mirroring of guideline values is present here as well.

The consideration of a potential individual preference of exposure level raises the question if a lower guideline implementation would be reflected in the audience exposure as well. Both arguments can be made as a physical reduction of the levels at the FOH directly relates to a reduction of potential areas of a supra-threshold exposure. However, if a 100dBA level is preferred, the audience may still naturally flow to these areas, although their availability may then be reduced. The observed ‘preference’ at least indicates a potential desired for exposure levels, and further research should be carried out to verify these observed trends as well as its shift relative to known comfortable listening levels of 83dBA [21].

Study limitations

The open environment setup of the experiments, introduced potential variation **[18]** in the sound levels recorded for which no proper control was implemented. These can be meteorological ones, as the observed rainfall at one event, but may extend further to the individual participants. As no individual tracking of the subjects was carried out, a limited control of their position with respect to the event exposure could be evaluated. Depending then on both the visitor count as well or simply the playback system **[6]** additional variation can be expected.

The observed variability is also subject of individual preference. Distance to the stage during a performance can vary, based for example on genre or line-up, leading to elevated exposure levels or alternatively reduced ones when an undesired performance takes place. Moreover, for each event only a small test group (maximum of 8) was used, serving as representation of the exposure at each event. The assumption is thus made that behavioral patterns of the audience are consistent across events. As a side note, behavior may have been influenced by the recording itself by making the participant aware of its exposed levels. An attempt to limit this was made by turning the information screen off on the displays of the Casella dBadges before and during exposure.

CONCLUSION

The observed variability, observed for $L_{A,eq,15min}$ cannot be captured sufficiently by an equivalent exposure $L_{A,eq}$ averaged over the entire duration. Part of the variability is lost by the averaging and hence also individual differences in terms of dynamic range observed. A masking of strong exceedances can occur resulting in misleading averaged exposure being still acceptable or close to guidelines. Additionally, small fluctuations in equivalent exposure can as well result in large exceedance shifts of the amount spent above WHO guidelines.

For the general behavior across subjects, most people (60%) were exposed to an equivalent level above the WHO 100dBA guideline with as well a significant portion of the exposure duration being at elevated levels above 100dBA (40%). However, the majority of time was spent around the 100dB guideline although individual differences in peak exposure occurred. A mimicking of the guideline in individual exposure behavior was thus apparent.

Peak detection as presented for $L_{C,peak}$ provides a complementary nature to the $L_{A,eq}$ as correlation between both was limited. A potential better quantification of the exposure both in terms of general exposure duration as well as peak levels can hence be expected. In return, allowing a more delineated definition of exposure and potential protection against it both in terms of average level, peaks and overall daily exposure (Pa^2h). Lastly, caution with consideration of accumulated exposure should be advised as well as observed values ranges above 2 times the earlier recommended WHO 4-hour exposure.

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