KES Transactions on Innovation in Music: Vol 1 No 1
Special Edition - Innovation in Music 2013 : pp.41-52 : Paper im13bk-004

Potential for reduction in noise exposure using closed back headphone monitoring for rehearsal – a pilot study.

Christopher Barlow[1] and Adam Wenman[2]
christopher.barlow@solent.ac.uk

[1] Solent Acoustics, Southampton Solent University, East Park Terrace, Southampton.
[2] Music Department, All Hallow's School, Farnham.

1. Abstract:

Student and young musicians often rehearse for long periods of time in small, often reverberant rehearsal spaces, resulting in high sound pressure levels, and have shown significantly higher rates of hearing loss onset than the general population. As a core element of rehearsal is quality of sound and good communication, musicians are often resistive to the use of hearing protection devices (HPDs).

This study analysed the noise levels musicians were exposed to during rehearsals, and whether use of individual monitoring using closed back headphones in rehearsal environments could result in a reduction of noise exposure for musicians. It was hypothesized that the sound isolation from the headphones would allow musicians to monitor at a lower level while retaining clarity.

Results indicated that the in-ear sound pressure levels did not significantly decrease overall, and in some cases significantly increased for musicians using headphone foldback. This also suggests that there may be potential increased risks issues with in-ear rather than loudspeaker monitoring for live music acts.

2. Introduction and Aims:

While people employed in the music industry (including orchestral musicians, session musicians and recording engineers) have been covered by the requirements of the Noise at Work regulations since 2008 [1] parts of the music industry have been slow to adapt to the change in legislation. In addition the majority of musicians are freelance, which means that they are not generally subject to the risk assessments that are required in places of regular employment, and can be unaware of the degree of exposure to which they are exposed.

Exposure to high levels of noise has long been recognised as a health hazard, with the long term result of noise-induced hearing loss (NIHL) in the majority of people. In particular, a common symptom is that of an audiometric "notch" between 4 to 6 kHz in which the hearing threshold is disproportionally reduced, though this is not always observed [2].

Musicians in all genres of music often work in noise levels which bring significant risk of long term hearing loss, unless appropriate protection is used [1]. A number of previous studies have demonstrated that musicians are at risk from hearing loss when they perform at live events [3], [4]. Young and student musicians tend to rehearse for long periods of time in small, often reverberant rehearsal spaces [5], [6], resulting in exposure to sound pressure levels which are hazardous to hearing. Student musicians in particular have shown significantly higher rates of hearing loss onset than the general population [7].

While in a live environment musicians come under Noise at Work regulations – even if freelancing, the Noise at Work regulations apply. Musicians will often wear a range of hearing protection including noise isolating in-ear monitors [4], and a number of high profile musicians (such as Pete Townshend and Chris Martin) have been part of campaigns to promote hearing protection [8]. However, in a rehearsal scenario, a high proportion of musicians do not wear appropriate hearing protection, due to a need to have clear communication and sound quality. This is in part due to the high costs of bespoke in-ear monitors and custom molded earplugs, as musicians often report not liking the fit of 'universal' earplugs [7].

It is common for musicians, studios and rehearsal spaces to have closed back headphones available. Closed back headphones often offer a good level of insertion loss (low penetration of outside noise), and it was hypothesized that using good quality closed back headphones would allow the clarity of mix required by the musicians, while providing enough sound isolation to reduce overall exposure to noise.

3. Background

The human hearing system does not respond equally to sound at all frequencies, and to compensate for this variability, noise measurements are made using representations of the human hearing system. The A-weighted dB L_P scale (otherwise known as dBA) [9] compensates for lower sensitivity at low frequencies (<1 kHz) than mid (1 to 6 kHz) and slightly reduced sensitivity at high frequencies of 8 kHz and above. A-weighting is applied as a filter curve to the 'flat' (Zero- or Z-weighted) measurements that are made by reference quality microphones.

> 'Exposures measured in dB*SPL* (dB L_P) will be somewhat higher than exposures measured in dBA, especially where there is a great deal of low pitched sound.' [3:p6]

The A-weighted filter is used as the basis of most noise measurements and legislation around the world. However, the relative frequency response of the human hearing system varies with overall level. The difference in energy level in the sound for sounds considered equally 'loud' at different frequencies varies more for low sound pressure levels than for high (ISO226:2003) [10]. In order to account for the reduced variation in perception for loud sounds, an alternative C-weighting filter is used by European regulations, which is based on the human response to sound around the 100 phon level (referenced to 100 dB L_P at 1kHz). This is used as the basis for assessment of impulsive noise at high levels under EU regulations (Directive 2003/10/EC) [11].

Noise exposure is cumulative over a period of time, and noise levels continually vary. In order to work out total exposure a time weighted average level is used to calculate 'equivalent' exposure over a period of time, giving the measure $L_{Aeq,\ T}$ (where T is the duration in hours). Calculations of overall noise exposure are calculated as a 'dose' within a given time period [12]. In order to get a standardized measure, all levels of exposure are normalized to an 8 hour average ($L_{Aeq,\ 8h}$) [11], based on the working day.

Several sources, including Action on Hearing Loss [13], the Health and Safety Executive (HSE) [14], and the American Speech-Language-Hearing Association (ASHA) [15] state that long-term exposure to sound pressure levels as low as 80 dBA poses some risk of damage to the hearing system for some people, with levels regularly above 85 dB L_{Aeq} posing a risk of mild hearing damage to most people.

As noise exposure is cumulative a calculation is applied to work out the relationship between exposure level and time of exposure to calculate when a listener reaches maximum daily 'dose'. Under the 3-dB "exchange rule" defined by ISO1999:2013 [16], with each doubling of sound energy (an increase of 3 dB), the time taken to reach the maximum daily dose reduces by half (table 1) [4]. Where noise exposure is highly variable, the measure may be normalised over a working week (five 8-hour days).

Average Level (dB L_{Aeq})	**Exposure time to reach upper action level**
85	8 hours
88	4 hours
91	2 hours
94	1 hours
97	30 minutes
100	15 minutes
103	7.5 minutes

Table 1. Maximum exposure time against average A-weighted sound pressure level (derived from ISO1999:2013) [16].

Permissible noise exposure levels take into account the effect of hearing protection, which is rated by the amount of insertion loss at each frequency. Audio insertion loss procedures test the amount of attenuation provided by different forms of HPDs and headphones. The process is defined by ISO 4869 part 4 [17] and involves the use of a relevant acoustical test fixture (ATF – Figure 1) or a head and torso simulator (HATS – Figure 2) with reference microphones on either side at the position of the ears.

Figure 1 (right) - G.R.A.S acoustical test fixture (G.R.A.S, n.d)
Figure 2 (left) - Head and torso simulator (HATS) (Bruel and Kjaer, n.d.)

The sound pressure level is first measured at one-third-octave-bands without hearing protection, as a reference point. The sound pressure level is tested with headphones on, and the result subtracted from the reference SPL. The results are then averaged, computing the mean for each ear, and the largest result is used.

4. Method

This study fell into 3 parts: In order to obtain generalised data, questionnaires were sent to a number of musicians to collect data on amount of weekly rehearsal (individual and group), most common closed back headphones used and self-reporting of any symptoms associated with hearing loss (reduced threshold, tinnitus, hyperacusis).

The method defined in ISO 4869-3:2007 [17] was used to measure the insertion loss of the most commonly used headphones reported by the respondents (Sennheiser ® HD205, Sennheiser ® HD203 and Sennheiser HD280 Pro, along with a pair of Optime III ear defenders for comparison). A Bruel and Kjaer ® 4128C HATS was used as the test fixture, with a full range active HK ® PA speaker driven by an NTI ® Minirator signal generator used as the sound source.

Finally, data was recorded from rehearsals of 8 different rock/pop bands in different spaces, each typical of their normal rehearsals, using their normal amplification with and without headphone foldback. A sample was taken of in-ear levels a number of individual band members rehearsing particular songs using headphone monitoring alongside normal amplification. Band members used their preferred closed back headphones (Sennheiser ® HD205) with the musicians having control over their own headphone settings.

Overall sound pressure levels in the rehearsal space was measured using a Bruel and Kjaer ® 2250 Sound Level meter, while individual levels were recorded using Cirrus Research ® Dosebadges™.

In order to monitor 'in-ear' levels, a passive split was taken from a set of HD205 headphones worn by the musicians to duplicate the output. An identical pair of HD205 headphones was placed on a Bruel and Kjaer ® 4128C Head and Torso Simulator (HATS) placed near to the musician to be in the same ambient soundfield. This was connected to a Bruel and Kjaer ® 2270 Sound Level Meter which was used to monitor the 'in ear' levels of the headphones as controlled by the performers.

In order to ensure that both sets of headphones were outputting equal levels, a pink noise test signal was sent to both sets of headphones via the headphone amplifier and splitter, with the output of both tested using the HATS. Variation in level was less than 0.5dB between headphones. Headphone output from a sample of musicians was recorded, along with simultaneous dosimeter data. This allowed direct comparison of the sound level recorded at the ear, compared to sound level outside the headphones.

5. Results

5.1 Questionnaire data

There were 30 respondents to the questionnaire, with 73% aged 18-24, 10% aged 32-45 and 17% aged 46-59. All were semi-professional or student musicians who perform pop/rock.

87% of the respondents reported having suffered from at least one symptom commonly associated with hearing loss with 47% believing damage may have occurred through performing at live music events. 17% reported having experienced noise induced pain.

Weekly solo rehearsal durations varied widely, with 44% reporting rehearsing 1-4 hours per week of solo rehearsal, 33% reporting 5-12 hours per week and 23% reporting more than 12 hours per week of solo rehearsal.

Reported duration of group rehearsal was lower, with 28% reporting 2 hours per week, 11% reporting 3 hours per week and 38% reporting 4 hours per week. The remaining respondents reported amounts up to 16 hours per week of group rehearsal.

5.2 Headphone insertion loss

The insertion loss at different frequencies for each of the headphones and the ear defenders is shown in Figure 3. Figures are unweighted, so the human hearing response has not been taken into account.

Figure 3 – Measured Insertion loss in dB of headphones and ear defenders across the audio spectrum (20Hz to 20 kHz)

As can be seen, the insertion loss of all the headphones is reasonably similar, with little reduction in sound pressure level below 800Hz, with 3-10 dB reduction from 1kHz to 1.4 kHz, and 10-25dB from 1.5kHz to 20kHz. There is slightly higher performance in the 200Hz to 800 Hz region for the HD280 headphones, though it does not match the performance of the ear defenders, or the stated performance of industry standard protectors such as ER-15 or ER-20 earplugs [18].

Insertion losses above 1kHz sit range between 10 and 30dB for the HD 205 and 203 models, so it is possible that they could attenuate enough sound to bring a musicians levels down to a safe level, as hearing is most sensitive to noise induced loss in the frequency range from 3-6 kHz [2], with the A weighted response accounting for this range in sensitivity.

5.3 Band exposure levels

The mean exposure levels in L_{Aeq} for a range of bands in normal rehearsal (i.e. not using headphones) for different positions sampled are shown in Figure 4.

Mean exposure levels in L_{Aeq} taken from dosebadges worn by a sample of band members during rehearsals with headphones are shown in Figure 5.

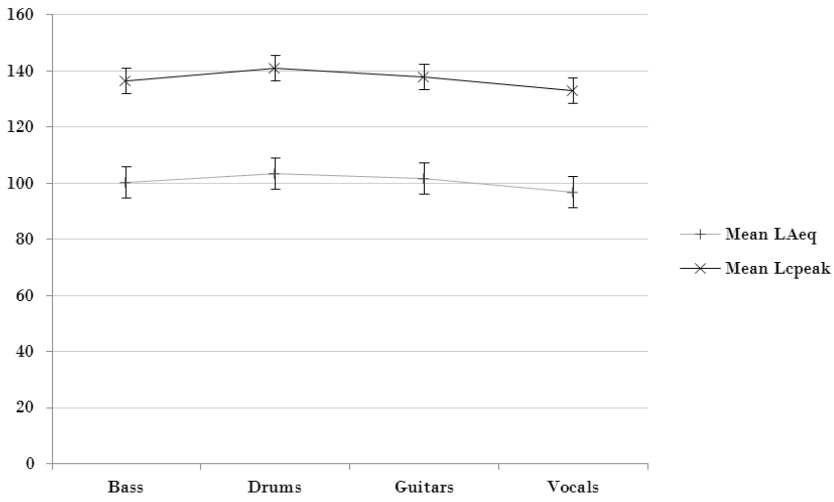

Figure 4: Mean Dosebadge exposure levels (dB L_{Aeq}) for rehearsal without headphones

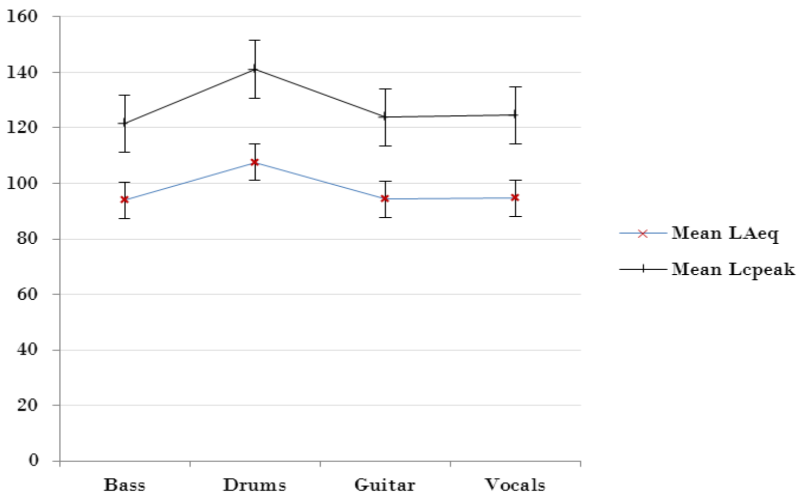

Figure 5: Mean Dosebadge exposure levels for sample rehearsal with headphones

A comparison of simultaneous in-ear (HATS) measurements of sound pressure level compared to external (Dosebadge) measurements for a sample of individual musicians is shown in Figure 6.

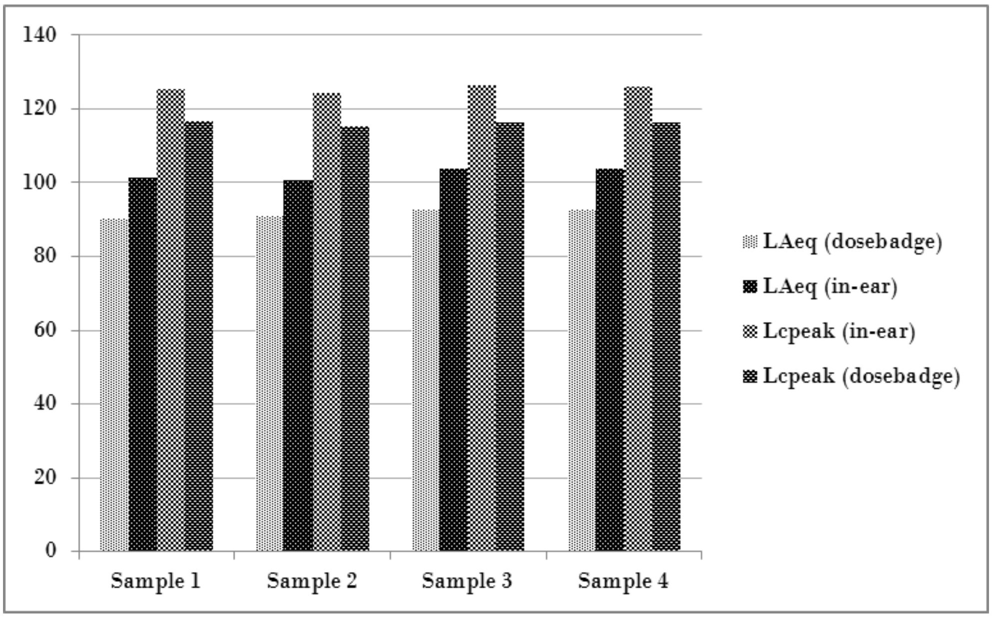

Figure 6: In–ear (HATS) vs external (dosebadge) exposure levels for individual musicians rehearsing with headphones.

6. Discussion

Results from monitoring of band practices indicate that band members are exposed to hazardous levels of noise if hearing protection is not worn. The calculation to transpose L_{Aeq} to a personal daily noise dose $L_{\text{EP},\,d}$ or weekly noise dose $L_{\text{EP},\,w}$ is given in the Control of Noise at Work regulations 2005 (equation 1) [19], derived from ISO 9612:2009 [20].

$$L_{\text{EP},d} = L_{\text{Aeq},Te} + 10log_{10}\left(\frac{T_e}{T_0}\right)$$

T_e = time of exposure (hours) and T_o = 8 hour time period (40 hours for $L_{EP,\,w}$)

Equation 1: Derivation of $L_{\text{EP},\,d.}$ [19:p9]

For those reporting 2 hours of band rehearsal (28%), a mean reading of between 97 dB L_{Aeq} (vocals) to 103 dB L_{Aeq} (drums) over 2 hours of rehearsal normalizes to a daily exposure of between 91 dBA $L_{EP,\,d.}$ (vocals) and 97 dBA $L_{\text{EP},\,d.}$ (drums), with levels for guitarists/bassists sitting in between at 94 dBA $L_{EP,\ d}$. This exceeds the upper action threshold, so as defined by ISO1999:2013 even a single weekly rehearsal of 1 hour is likely to cause some long term hearing damage [16]. If this was the only noise exposure in a 1 week period, this would equate to a weekly noise exposure $L_{EP,\ w}$ of 84 dBA for vocals, 94 dBA for drums and 91 for guitarists, putting vocalists just under the upper action level, but both drummers and guitarists above it. As the majority of respondents reported considerably higher durations of group rehearsal, and also solo rehearsal, it is inevitable that all will exceed the upper action threshold for weekly exposure.

For musicians reporting 4 hours per week of band rehearsal (38%), this equates to an LEX of 94 dBA $L_{EP,\ d}$ for vocals, 97 dBA $L_{EP,\ d}$ for guitarists/bassists and 100dBA $L_{EP,\ d.}$ for drums. Alternatively this could be assessed as a weekly exposure of 87 dBA $L_{EP,\ w}$ for vocals, 90 dBA $L_{EP,\ w}$ and 93 dBA $L_{EP,\ w}$ for drums – all of which exceed the upper action level. A large proportion of musicians reported even higher durations of rehearsal, so it is clear that any musicians rehearsing without some form of hearing protection are putting themselves significantly at risk.

Peak levels are also exceeding levels of recommendation – the maximum levels recommended by the Control of Noise at Work regulations are 135 dBCpeak (lower action level) and 137 dBCpeak (upper action level) [19]. Bass, drums and guitar all exceed the lower action level, with drums exceeding the upper action level.

The results from rehearsals in which musicians wore headphones for monitoring are interesting. It appears from the Dosebadge data that the overall 'external' levels have reduced, with a mean change in level of around -3 dB. This is offset by the fact that although guitar and bass reduced amplitude by around 6dB, drum levels actually increased by 4 dB compared to the rehearsal without headphones. A student's t-test shows that the mean variation in level is not statistically significant ($p>0.05$).

The implication is that despite using headphone foldback, the musicians have not changed the overall level of amplification in the room by a large amount. This may be for a number of reasons, the most likely of which is the competition from levels of the acoustic drum kit, which cannot be 'turned down'.

When the data is assessed for the sample of musicians (guitarists and vocalist) whose in-ear levels were assessed using the HATS, a further interesting point appears. Although the levels in the room have decreased slightly, the average level at the ear (dBA L_{Aeq}) in *each case* was higher by around 10 dB, with a student's t-test showing the difference to be significant ($p<0.05$). This result is replicated by the dB L_{Cpeak} values, which also increased significantly, although in these cases L_{Cpeak} was below the action threshold for both samples. Although each sample was undertaken over a short period of time (1 song), if extrapolated to the duration of weekly rehearsal, this result suggests that the use of headphones could increase rather than decrease risk of noise related hearing damage.

As the levels at the ear are ~10dB higher than the levels recorded by the dosebadges, the contribution of the external sound to the in-ear levels will be minimal, [9]. It is suggested therefore that that this increase in level is caused by the fact that the sound isolation offered by the headphones is not linear across the frequency range. This would lead to significant leakage of bass sounds through the headphones into the ear, but less treble leakage, so that the musician is hearing a more 'muffled' sound, and is consequently turning up the amplification on the headphones in order to get a 'clear' mix. As acoustic drums cannot be turned down, the ambient levels in the room have also remained high, resulting in a need to boost the in-ear mix for clarity.

7. Conclusion

Overall results suggest that there is a key need for musicians to use some form of hearing protection within the rehearsal as well as the live environment, with even small amounts of group rehearsal time placing musicians above the recommended limits for weekly personal noise exposure ($L_{EP,\,d}$) [20].

However, rather than reducing the risk of noise exposure, the use of common closed back headphones for rehearsal foldback did not significantly reduce the sound pressure levels within the rehearsal rooms. Furthermore in ear levels significantly *increased* for a sample of musicians using headphone foldback rather than in ear monitoring.

It is suggested that in the event of custom molded in-ear monitors being unaffordable to young or non-professional musicians, they should use hearing protection devices at all times when rehearsing amplified instruments or drums, particularly in a group environment. From the results of this study it is recommended that 'musician's earplugs' would be a more effective means of protecting the ear than use of closed back headphone monitoring.

As musicians chose to turn up their own monitoring to levels significantly higher than the 'room' level, this result suggests the possibility of increased risks with using in-ear rather than loudspeaker monitoring for live music acts. Further study is needed to assess the use of headphones and in-ear monitors with a high degree of sound isolation for foldback in music performance environments.

8. References

[1] Patel J. Musician's Hearing Protection—A Review. Norwich: The Health and Safety Executive, HMSO (2008).

[2] Borchgrevink HM. Does health promotion work in relation to noise? Noise Health; 5(18):25-30. (2003)

[3] Peters C, Thom J, Mcintyre E, et al. Noise and hearing loss in musicians. Commission for Safety and Health in Arts Production and Entertainment, (SHAPE): Vancouver (2005).

[4] Health and Safety Executive. Sound advice—Control of noise at work in music and entertainment. Norwich: HMSO (2008).

[5] G. Zepidou, S. Dance. An orchestra's noise exposure, Proceedings of Noise in the Built Environment. Institute of Acoustics 32(3), Ghent (2010).

[6] Barlow, C., Potential Hazard of hearing Damage to Students in Undergraduate Popular Music Courses. Medical Problems of Performing Artists. 25 (4); pp175-182. (2010)

[7] Barlow, C., Evidence of noise-induced hearing loss in young people studying popular music. Medical Problems of Performing Artists. 26 (2); pp96-1.1. (2011)

[8] Action on Hearing Loss. Loud Music Campaign [website]. (2013) Available at URL: http://www.actiononhearingloss.org.uk/loud-music.aspx. Last accessed 26/10/2013.

[9] Peters, R, Smith B.J. and Hollins, M. Acoustics and Noise Control. Harlow: Prentice Hall (2011)

[10] ISO 226:2003. Acoustics -- Normal equal-loudness-level contours. International Organization for Standardization, Geneva. (2003).

[11] Directive 2003/10/CE of the European Parliament and of the Council of 6 February 2003 – The minimum health and safety requirements regarding the exposure of workers to the risk arising from physical agents (noise). (2003). Available online at: https://osha.europa.eu/en/legislation/directives/exposure-to-physical-hazards/osh-directives/82

[12] Barron, R Industrial Noise Control and Acoustics. New York: Marcel Dekker. (2002).

[13] Action on Hearing Loss. Noise Exposure–The Facts. London, RNID Press, (2012). Available online at: http://www.actiononhearingloss.org.uk/your-hearing/about-deafness-and-hearing-loss/types-and-cause-of-hearing-loss/noise.aspx. Last accessed 27/10/2013.

[14] Butterfield D. Measurement of noise levels that staff are exposed to at live music events. Norwich: Health and Safety Executive, HMSO; 2006.

[15] American Speech-Language-Hearing Association. Noise and hearing loss prevention [website]. Rockville, MD: ASHA; (2013). Available at: http://www.asha.org/public/hearing/disorders/noise.htm. Last accessed 27/10/2013.

[16] ISO 1999:2013 Acoustics -- Estimation of noise-induced hearing loss. International Organization for Standardization, Geneva. (2013).

[17] ISO 4869-3:2007. Acoustics -- Hearing protectors -- Part 3: Measurement of insertion loss of ear-muff type protectors using an acoustic test fixture. International Organization for Standardization, Geneva.

[18] Advanced Communications Limited. ER series technical specification. (2013). Available from URL: http://www.acscustom.com. Last accessed 26/10/2013.

[19] UK Statutory Instrument 2005 no 1643. The Control of Noise at Work Regulations 2005. Norwich: HMSO (2005).

[20] ISO 9612:2009. Acoustics: Determination of occupational noise exposure—engineering method. Geneva: International Organisation for Standardization. (2009).