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Face the Music: A 12 year study of the sound of performance and hearing of classical music

Stephen DANCE[1]; Doug SHEARER[1]; Georgia ZEPIDOU

[1] London South Bank University, UK

[2] AECOM, London, UK

ABSTRACT

The Acoustics Group has collaborated with a leading UK conservatoire since the enforcement of the Control of Noise at Work Regulation in 2008. Every new student has attended an awareness course on the sound of performance and hearing, undertaken hearing health surveillance and has been questioned as to their aural history. In addition, the sound of performance, in terms of individual practice, rehearsal and performance has been measured for all types of instruments. This dataset has been analysed to determine the hearing acuity of classical musicians and their occupational sound exposure. A paper will be presented on this analysis which suggests that self produced music has much less impact on hearing than typical noise exposure, as given in ISO 1999:2013.

Keywords: Sound exposure, music, audiometry

1. INTRODUCTION

Since the implementation and enforcement of the European Union Physical Agents Directive (Noise) [1] the Acoustics Group has collaborated with a conservatoire creating a noise team formed from administrators, scientists, and senior management [2-9]. Our challenge was to allow these highly talented artists to practice, rehearse, and perform safely during their entire career. This on-going project has been running for twelve years involving 3935 musicians measuring sound exposure from each instrument group and the hearing acuity of each and every student. Of the original population a total of 229 students were sampled to be retested to assess their hearing acuity after they had completed their four years of studies. At each occurrence the students were questioned as to their aural environment. Presented is a comparison of their hearing acuity and measured sound exposure dose.

2. APPROACH TO HEALTH SCREENING

The conservatoire took an inclusive view whereby every new student had to compulsorily take an automated audiometric screening test during the first week of his or her studies, Fresher's week. The retest takes place at the beginning of their last term, so as not to interfere with final examinations. In addition, a one-to-one interview was held with each student, as well as an otoscopic examination and feedback on the health surveillance results.

The test was based on a pure-tone air conduction Bekesy test (frequencies 500 Hz to 8 kHz), using calibrated Amplivox automated screening audiometers with TDH49 audiocups. The test was conducted in the audiometric soundproof booths at the Acoustic Laboratory of London South Bank University (LSBU); see Figure 1. Both booths used met the ambient noise criteria given in ISO 8253-1:2010 [10]. Once the test and questionnaire were completed, each audiogram was categorised according to the Health and Safety Executive (HSE) categorisation scheme [11]. Students photograph a copy of their audiogram with the original held by the conservatoire. Results were discussed individually with each student and advice has been given on protection from sound exposure, including advice on most suitable hearing protection option based on the instrument played. It should be noted that every student since 2016 has been given a pair of

[1] dances@lsbu.ac.uk

Happy Ear Musician Earplugs, SNR=25 dB [12]. The dosimetry presented was undertaken in 2010/11.

Figure 1: Audiometric booth showing response button and Audiocup TH49 headphones Copyright Stephen Dance 2014.

Table 1:Health and Safety Executive hearing categorisation scheme [11].

Category	*Calculation (dBHL)*	*Action*
1 **ACCEPTABLE HEARING ABILITY** Hearing within normal limits	Sum of hearing levels at 1, 2, 3, 4 and 6 kHz.	None
2 **MILD HEARING IMPAIRMENT** Hearing within 20th percentile. May indicate developing NIHL [ISO 1999].	Sum of hearing levels at 1, 2, 3, 4 and 6 kHz. Compare value with figures given for appropriate age band and gender.	Warning
3 **POOR HEARING** Hearing within 5th percentile. Suggests significant NIHL. [ISO 1999]	Sum of hearing levels at 1, 2, 3, 4 and 6 kHz. Compare value with figures given for appropriate age band and gender.	Referral
4. **UNILATERAL HEARING LOSS**	Difference in the sum of hearing levels at 1,2,3,4 kHz of each ear > 40 dBHL	Referral
5 **RAPID HEARING LOSS** Reduction in hearing level of 30 dB or more, within 3 years or less. Such a change could be due to noise exposure or disease.	Sum of hearing levels at 1, 2, 3, 4 and 6 kHz.	Referral
6. **EARLY SIGNS OF LOSS**	Hearing loss of at least 20 dB at any frequency	Caution

For hearing acuity to be categorised as good hearing the summed hearing loss (dBHL) for each ear should be less than 50 for men and 45 for girl assuming they are 18-25 years old [11]. This is the age range for the students in this investigation.

3. NOISE DOSIMETRY

3.1 Standards and Guidance

The Noise at Work Regulations 2005 [11] following the EU Directive 2003 [1] sets the following levels for noise exposure of an employee. Of course students are not employees but were considered so for the research project.

Table 2 Exposure limit values and Exposure action values set by the Noise at Work Regulations 2005 [11]

First action level (lower exposure action value)	$L_{EP,8h}$ = 80 dB(A)	L_{peak} = 135 dB(C)
Second action level (upper exposure action value	$L_{EP,8h}$ = 85 dB(A)	L_{peak} = 137 dB(C)
Exposure limit values	$L_{EP,8h}$ = 87 dB(A)	L_{peak} = 140 dB(C)

Noise monitoring is considered an essential part of a risk assessment for classical musicians in orchestras, music schools, etc. By carrying out on-site noise measurements (although in some cases these may not be necessary), the extent of a noise exposure problem can be established. Specifically, noise monitoring can identify the 'problematic areas' within a venue or music school, or individuals that are likely to be overexposed. A plan can then be tailored using various types of noise control measures to mitigate the exposure of the musicians without compromising the quality of performance [13].

British Standard BS9612:2009 [14] provides an approach to the determination of occupational noise exposure from noise level measurements. Although it analyzes all major steps that should be taken during the assessment procedure, it is a general guidance, which is not specifically related to musicians. As this particular assessment requires different strategies and decisions to be made for each music sector, music repertoire, venue, etc., two documents have been prepared that help and guide employers to carry out their own measurements while at the same time, a common approach by all institutions, could lead to a large database on noise exposure of musicians. These two documents are 'Sound Advice: Control of noise in music and entertainment' [15] and 'A Sound Ear II. The Control of Noise at Work Regulations 2005 and their impact on orchestras' [16]. Both these documents inform on dangers associated with musicians' noise exposure and give guidance on how to assess and control/reduce noise exposure. These have been complimented by Toolkits produced by the BBC for Musicians [17] and for Managers [18].

3.2 Dosimetry

The project consisted of assessing the musicians' diaries to evaluate their noise exposure during typical activities. Various assumptions were necessary for the effective playing time to be calculated. The students' diaries were assessed activity-by-activity in order to obtain a daily personal noise exposure dosage based on the Health and Safety Executive (HSE) guidelines using a "% points" system for each activity. The students provided the following information: music piece performed, rehearsed or practiced, number of people/instruments playing and the room used. Thus it was representative of typical practice or teaching for a particular instrument or voice. The measurements were taken using five dosimeters, CR 110A, all were calibrated before and after each measurement.

The project covered 49 principal instruments, unfortunately only 20 were returned by the students. Of these only 18 were retested during their studies: 5 Brass, 2 Jazz, 3 Woodwind, 1 Keyboard, 4 Strings, 2 Voice, 1 Percussion, see Figure 2.

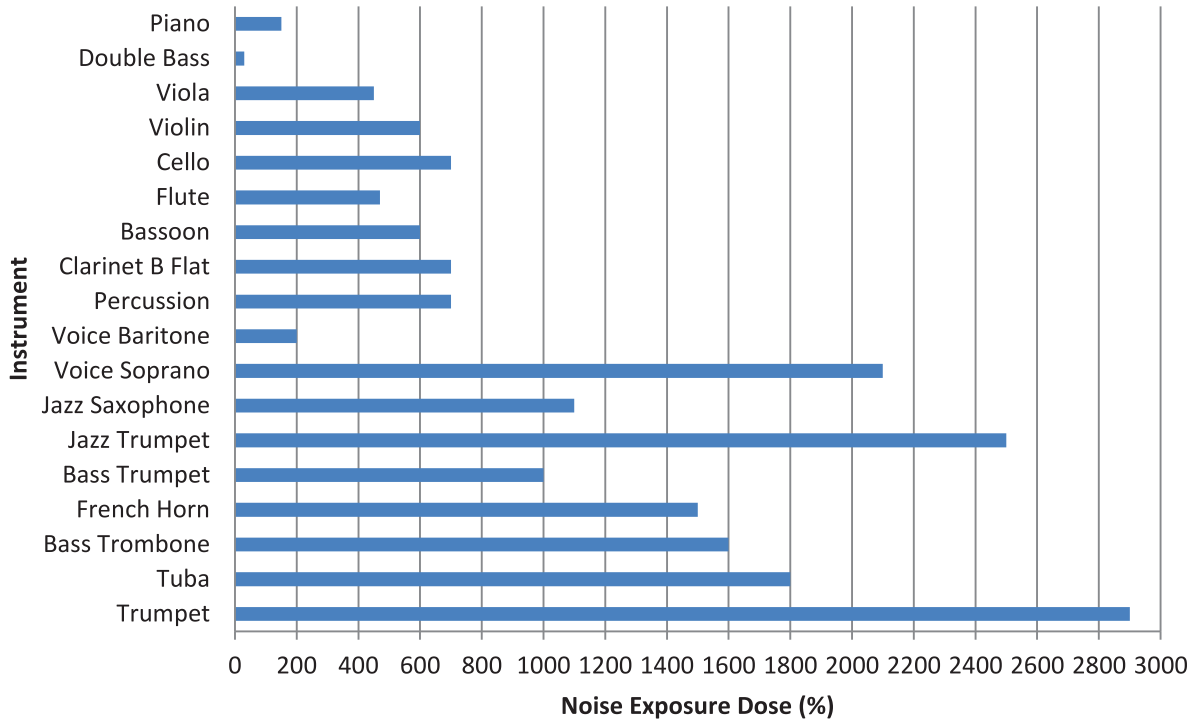

Figure 2. Noise exposure dose of 15 musicians taken during a typical day at the Royal Academy

The calculated noise exposure dose values were found to be above the legal limits [11] in nearly all cases. Therefore, it was initially recommended that the conservatoire implement a noise risk mitigation strategy and offer all students free musician earplugs. By combining the instruments into groups an overall noise exposure per orchestral section can be calculated, see Table 3. For completeness, Table 3 also showed the typical hours played by each instrument group based on the questionnaire responses.

Table 3 Noise Dose (%) per Instrument Group

	Brass	Jazz	Voice	Percussion	Woodwind	Strings	Piano
Noise Dose (%)	1760	1800	1100	700	590	445	150
Daily Playing (hours)	4.0	2.9	2.5	5.3	4.4	5.0	4.9

The daily dose received results were as expected, the highest values were found for the Brass, Vocalist and Jazz sections which corresponded with the highest average noise levels [19-21]. We know from the questionnaire results that the musicians typically play between 2.5 and 5.3 hours per day dependent on instrument group although the Noise Dose are based on $L_{EP,D}$ derived numbers based on an 8 hour day.

4. AUDIOMETRY DATA

Approximately 30 students are randomly sampled each year and retested at the end of their course. Based on the questionnaire results the average age on entry was 19.1 years and for the retest, 22.6 years. Exit audiometry was undertaken on 229 students, 2011-2018, these have also been grouped into sections to give statistical significant numbers, see Table 4.

Table 4. Instrument Groups with years studied, number retested, entry and exit summed hearing loss per ear and change in hearing (dBHL)

	Years Studied	Number Retested	Entry Left (dBHL)	Entry Right (dBHL)	Exit Left (dBHL)	Exit Right (dBHL)	Change Left (dBHL)	Change Right (dBHL)	Averaged Change in Hearing (dBHL)
Brass	12.3	47	7.86	8.07	6.4	1	1.46	7.07	4.265
Jazz	9.9	19	3.11	-12.25	-5.9	-7.09	9.01	-5.16	1.925
Percussion	13.2	12	4.25	2.58	-8.08	-5.09	12.33	7.67	10
Piano	19.2	32	9.14	3.52	-1.73	-6.28	10.87	9.8	10.335
Strings	13.4	56	-2.73	-2.8	-6	-11.64	3.27	8.84	6.055
Voice	13.7	12	6.06	7.56	-2.27	-8.64	8.33	16.2	12.265
Woodwind	12.3	51	1.8	-4.78	-6	-2.85	7.8	-1.93	2.935

From the dataset it can be seen from Table 4 that Pianists have played the longest time and the Jazz players the shortest, the other instrument groups have played for a similar length of time, 13 years. There were four instrument groups with a significant number of participates, (Brass, Piano, Strings and Woodwind) and these will be further analysed, n>30. All audiometry data presented in Table 4 uses the summed hearing losses, 1, 2, 3, 4 and 6 kHz per ear in accordance with HSE guidance [11] except for the final column, Averaged Change in Hearing, which combines the results for each ear.

For each group the students' entry averaged summed hearing loss was compared to the exit result. A positive result in the Change column meaning the group's hearing had improved on average. It can be seen from Table 4 that after 3.5 years of playing at the conservatoire all groups had an overall improvement in their hearing acuity, ranging from 1 to 12 dBHL for the left ear. For the right ear there were only two exceptions: the right ear of the Jazz group, a 5 dBHL loss and the right ear of the Woodwind Group, a 2 dBHL overall loss. It should be noted that only 19 musicians were included in the Jazz group.

5. ANALYSIS OF THE NOISE DOSE AND AUDIOMETRY DATA

The hearing dataset can now be compared to the noise dosimetry collected on students to see if there is a relationship between music and hearing. There is a known relationship between noise and hearing given in ISO 1999:2013 [22].

5.1 Initial Music Dose Hearing Loss Model for Classical Music Students

If only the groups with n>30 are included in the analysis and the music dose is converted into ($L_{EP,\,d}$) then the music and hearing relation can be seen, see Figure 3.

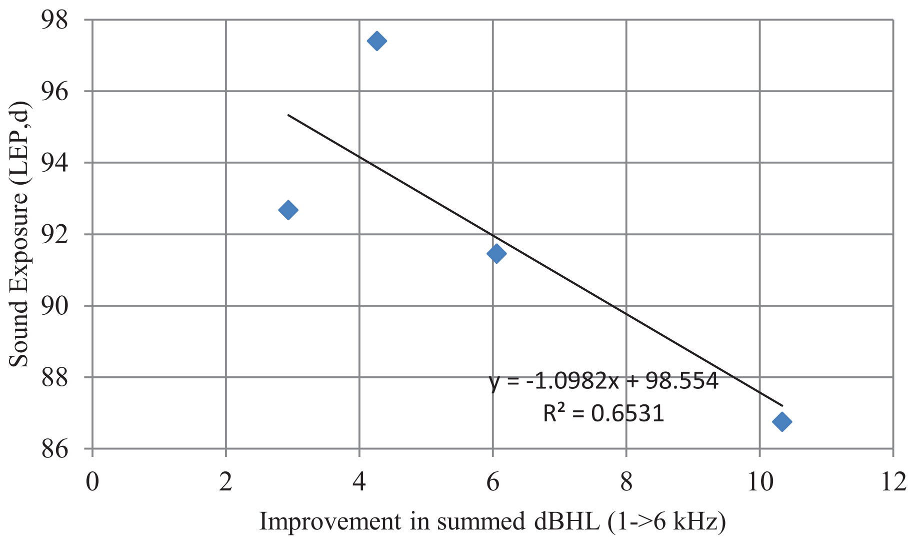

Figure 3. Relationship between music dose and hearing for 4 instrument group, 3.5 years of study

Figure 3 show a clear relation between hearing and music exposure creating a hearing loss model for musicians, approximately 2dBHL less gain for every 2 dB increase in daily sound exposure level, $L_{EP,d.}$. However, instead of hearing loss the data clearly shows a hearing gain after 3.5 years of intensive study. The least gain was for the woodwind rather than the louder brass which indicates that in an orchestral setting, where for symphonic music they sit in front of the brass, the woodwind would be a greater risk. This would generate a hypothesis that in a pit setting the strings would be at greater risk of hearing damage [23]. These results are in contrast to the positive result presented in ISO 1999:2013 for noise exposure levels and hearing loss [22].

5.2 Verification of the Music Dose Hearing Loss Model for Classical Music Students

To test the hearing loss model the next largest instrument group, Jazz n=19, was added to the dataset producing Figure 4.

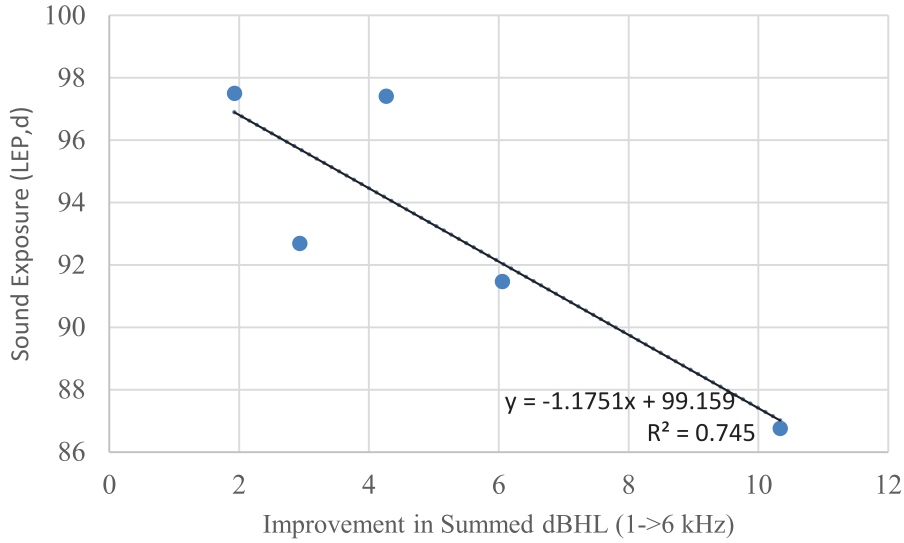

Figure 4. Relationship between music dose and hearing for 5 instrument groups, 3.5 years of study

When the Jazz group hearing loss data was added to the hearing model, see Figure 4, the fit was within 1 dB for the sound exposure level, $L_{EP,d}$ prediction. Of course this prediction model would improve when more musicians have been retested; this would allow the other two instrument groups to become statistically significant. It could also be improved by adding professional orchestral musicians to the dataset.

5.3 A Potential New Music Exposure Level

The noise exposure of the students was excessively high, see Table 3, and yet their hearing was found to be highly acute, see Table 4. It was found that 5 out of 14 of the grouped ears had a negative hearing loss, or hearing gain. This was investigated in depth in [2]. This would indicate that the current noise exposure limits, see Table 2, may not be appropriate for self produced music exposure. It was shown in Table 4 that the students have been exposed for more than 13 years to their instrument, a long term exposure, yet there is no associated noise induced hearing, Table 4.

It could then be hypothesized that a new limit could be introduced called The Music Exposure Limit. The origins of the noise exposure limits come from six studies, 1968-1973, on industrial workers. These datasets were then used to inform the regulations [11]. These industrial workers would have had a stress response to the noise, the noise being a by-product of the work undertaken. In contrast self produced music is the point of the work and hence should have a different response. However, it has been found that under orchestral or pit conditions the players have an 80% response to the question, “Have you suffered hearing loss” based on 367 respondents [24]. This demonstrates that potentially noise is non-controlled self-produced music, and as such should keep the same noise exposure limit value of $L_{EP,d}$ of 85 dBA. The opposite view, Music is Noise, has recently been put forward by Chasin [25] although he did not put forward evidence and all literature referenced was sensorineural in nature with no reference to music as the sound source.

Based on the dataset collected a $L_{EP,d}$ of 95 dBA could replace the current 85 dBA limit with a 3 dB exchange rate. If the sound exposure levels recorded were reanalyzed with the new limit would reduce the music dose ten-fold. This music dose concept will need further evidence along the same lines as ISO 1999. This assumes that the musician was largely exposed to their own music or a similar music section; as is the case at a conservatoire. Thus the context of the sound is key. For orchestral and pit settings if the musician is not the primary sound source then the 85 dBA limit should be applied. This is further evidenced by the hearing results of Piano Accompanists, n=70, compared to the Pianists, n=302 [2]. It was found that accompanists had an additional 3 dBHL of Permanent Threshold Shift at 6 kHz for the right ear. This was due to vocalists singing at 1100% noise dose into the accompanists’ right ear over a 2-year period [3].

6. CONCLUSIONS

A leading UK conservatoire has actively pursued hearing health surveillance over the past 12 years testing 3935 students all at the commencement of their studies. A sample of 229 students was retested at the end of their studies, 3.5 years later. These students' audiograms were combined into 7 instrument groups. It was found that on average each instrument groups' participates had improved hearing, 2 to 12 dBHL overall as averaged for both ears over 1 to 6 kHz.

At the same time dosimetry was undertaken on 49 students of which 18 performers completed their dose diaries; the results showed that 17 out of 18 musicians had excessive noise exposure, 150% to 2900% on a daily basis. It was also found that musician play, rehearsal and perform 2.5-5.3 hours a day dependent upon instrument.

The hearing of the students was then combined into 7 instrument groups, although only 4 instrument groups had n>30 and these were compared to the recorded instrument group sound dose. This analysis showed a very clear trend, for every 2 dBA increase in $L_{EP,d}$ there was a reduction in the improvement in summed hearing (1 to 6 kHz) of 2 dBHL. It should be noted that according to ISO 1999:2013 hearing should deteriorate with excessive noise exposure. The model was verified by testing the Jazz group where the music exposure prediction was within 1 dB of that predicted based on the audiometry group results based on 19 participates.

Further work would involve introducing professional orchestral musicians to the data set, as currently only 18-25 year olds are represented. The professional musicians would be older and should have been regularly tested as part of hearing health surveillance [8] and O'Brien *et al* [24]. It should also be noted that O'Brien *et al* did state that orchestral music and its affects is a complex subject [26].

Finally, what can be stated is that studying music at the highest level makes you a better listener. The Bekesy audiometric test is essentially a listening response test, and as such perhaps a different approach should be taken. One such approach that could be used as part of best practice is regular longitudinal Otoacoustic Emissions testing to supplement the audiometric data.

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