Face the (Unamplified) Music: Key findings for musicians.

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Abstract

Music is complex. There are risks to hearing health associated with playing due to excessive sound exposure. Face the Music is an on-going cross-sectional project to assess the risks to unamplified classical musicians. Key findings over the first fifteen years are presented based on the research undertaken with a leading conservatoire on more than 5000 classical music students. The work covers hearing health surveillance, education and awareness, sound exposure, and new technology. The future of the research programme is discussed along with opportunities in objective hearing health assessment and new acoustic solutions. A lot has changed in fifteen years, but the research was driven by a change in United Kingdom legislation. It is hoped that the research results can inform future regulation.

I. INTRODUCTION

The Control of Noise at Work Regulations 2005 (CoNAWR) [1] were introduced to protect UK employees from health risks associated with noise. The 2005 regulations replaced the 1989 Noise at Work Regulations and introduced new, stricter requirements for action to be taken by employers.

These include action to protect workers at levels of sound 5 dBA lower than those in the 1989 regulations, as well as health surveillance for employees regularly exposed to sound levels above 85 dBA. The CoNAWR2005 were enforced in 2006 for all sectors other than the entertainment sector who were allowed an additional 2-year transitional period. Hence a key date is 2008, a year in which O'Brien *et al* stated in their conclusion on orchestral music, "music is complex" [2]. This was the start of the Face the Music project, a project focused on unamplified music.

Face the Music was formed through a collaboration with a world leading conservatoire, the Royal Academy of Music, London. There was leadership from the top of the organisation from the outset with the welfare of students coming first, even though technically the CoNAWR is only relevant to those who are employed. As such a long term plan was formed to educate and inform the students, undertake to assess ever student's hearing, assess the sound exposure risk, and to develop solutions to minimise the hearing health risks associated with playing through application of acoustic technology. This paper focuses on education, sound exposure and hearing health surveillance results.

II. LITERATURE REVIEW

It is known that excessive sound exposure can result in Noise Induced Hearing Loss (NIHL) typically occurring at 4 kHz [3]. Lutman *et al* [4] calculated that approximately half of NIHL occurs within the first three years of excessive sound exposure with the remaining NIHL occurring over the following 40 years. This was based on analysis of ISO 1999 [5]. Therefore, it is critically important to protect new employees or alternatively university students at the earliest opportunity. This can be accomplished through automated hearing health surveillance using an audiometer in a soundproof room [6]. Either the Bekesy or Hughson-Westlake Test methodology for screening for hearing loss can be used. Both approaches use pure tones varying with frequency and amplitude. The test typically takes a subjective 10 minutes to complete after familiarisation.

The other major cause of hearing loss is presbycusis, but this is minimal (< 1dBHL at any frequency) for 18-25 year olds [7]. The CoNAWR were developed based on research in the effects of occupational noise exposure on hearing health which was based on industrial environments and did not include effects of entertainment sound or music exposure. This was due to the absence of relevant data. Enforcing the regulations on the entertainment sector is particularly difficult due to the nature of their work and sound being a deliberate product rather than a byproduct of the work undertaken.

III. THE PROGRAMME

Since 2007, through a long-term collaboration with the Royal Academy of Music (RAM), approximately 330 students each year have been assessed using the standard Bekesy pure tone screening audiometric (PTA) test procedure as part of a hearing health surveillance programme [8].

This paper will introduce key results determined from a long running questionnaire survey, sound exposure measurements and audiometric screening. In addition, the value of newly introduced educational tools to enhance awareness, new assessment methodologies and the long term effect of a prolonged campaign to raise awareness of the risk of excessive sound exposure are detailed.

A. Key Findings in Awareness and Tools.

RAM students attended a series of compulsory in-person seminars during Freshers' week (2007-2019) to inform the cohort of the risks associated with music and the sound of performance. The cohort were split into four instrument groups so that the talk could be more targeted and hence of more interest. Each one hour seminar included demonstrations using HearLoss software [9], how to correctly fit hearing protection, and later how to use your smartphone. Recently video-on-demand technology has replaced the in-person seminar.

The smartphone was introduced in 2007, during the following year sound apps were created, such as Studio Six Digital [10] and Faber Acoustical [11]. In 2010 testing was undertaken in the field and under laboratory conditions to establish their accuracy. Less than a 2 dBA difference with a Class 1 sound level meter for noise and music was found in terms of the average sound level using the LAeq,T acoustic parameter [12]. However, peak levels were not recorded accurately. In 2014 this was confirmed by a separate independent study [13]. With the increased prevalence of smartphones well written apps have become a much welcomed educational tool.

Concurrently, the authors found that the current generation of dosimeter used to measure sound exposure were really focused on heavy industry use: mining, construction, oil, and manufacturing. Hence, in 2010 in collaboration with Audio^{3} a new smaller and lighter dosimeter was designed, developed, tested and produced, Soun**dB**adge [14]. This allowed a less intrusive measurements to be taken in a more discrete manner [15]. The device importantly complied with the appropriate dosimetry instrumentation standard [16].

In 2021 the Royal National Institute for the Deaf (RNID) produced a Noise in Speech web based tool that could be accessed through a smartphone. The tool requires headphones/earphone to be worn for the test procedure to provide accurate results. This is an uncalibrated test but uses a relative level methodology and has so far produced 500,000 test results [17] creating further awareness.

B. Key Findings from the Questionnaire Survey.

A 10 minute one to one interview was held with every RAM student, n=5300, to complete a short questionnaire. The interview was undertaken just after the hearing assessment and used to confirm the reasonableness of those results. The average age of the students upon entry to the undergraduate and postgraduate courses was found to be 22.0 years with a 48:52 male/female split. The average time learning their instrument before starting their studies was 12.7 years, although this slight differs per instrument with pianists having the longest time of study, 15.3 years and brass players the shortest at 8.3 years. There was also a significant difference in the length of time the instrument was practiced or performed varying from 30 minutes for the vocalists, 3 hours for the brass, to 4 hours for the woodwind, 6 hours for the strings and 8 hours for the pianists.

The prevalence of listening over headphone/earphones to music was 96.2% (2021-2023 data n=612), 100% of those students had a smartphone. Wireless earphones were introduced by Apple in September 2016. Those listening loudly was found to be 36.3%, that is above the 85 dBA alert level. It should be noted that the iPhone has been able to calculate sound level headphone/earphone use since iOS 15 and more recently using the Apple Watch [18]. These tools were used in the Apple Hearing Study in collaboration with University of Michigan School of Public Health where 1 in 3 users, n=130000, were found to have sound exposure, LAeq, 24 hour above 70 dBA [19]. The smartwatch has an advantage over the smartphone in that it is normally clearly exposed to the environment and hence the measurements are inherently more reliable than using smartphone captured data.

C. Key finds from Dosimetry.

One of the first assessments undertaken, 2008-9, was the measurement of daily sound exposure level, in terms of $L_{Ep,d}$. These measurements were taken using calibrated Cirrus Research CR110A dosimeters. A sample of 18 students were selected representing the full range of instruments [20].

The key finding was that all but one musician had a significant noise exposure dose, see figure 1, greater than 100% dose using the calculation.

$$Dose = 2^{\left(\frac{L_{Aeq,T} - 85}{3}\right)*\left(\frac{T}{8}\right)100\%}$$

Where $L_{Aeq,T}$ is the average equivalent A weighted sound level in (dB), T is the measured time period (hours).

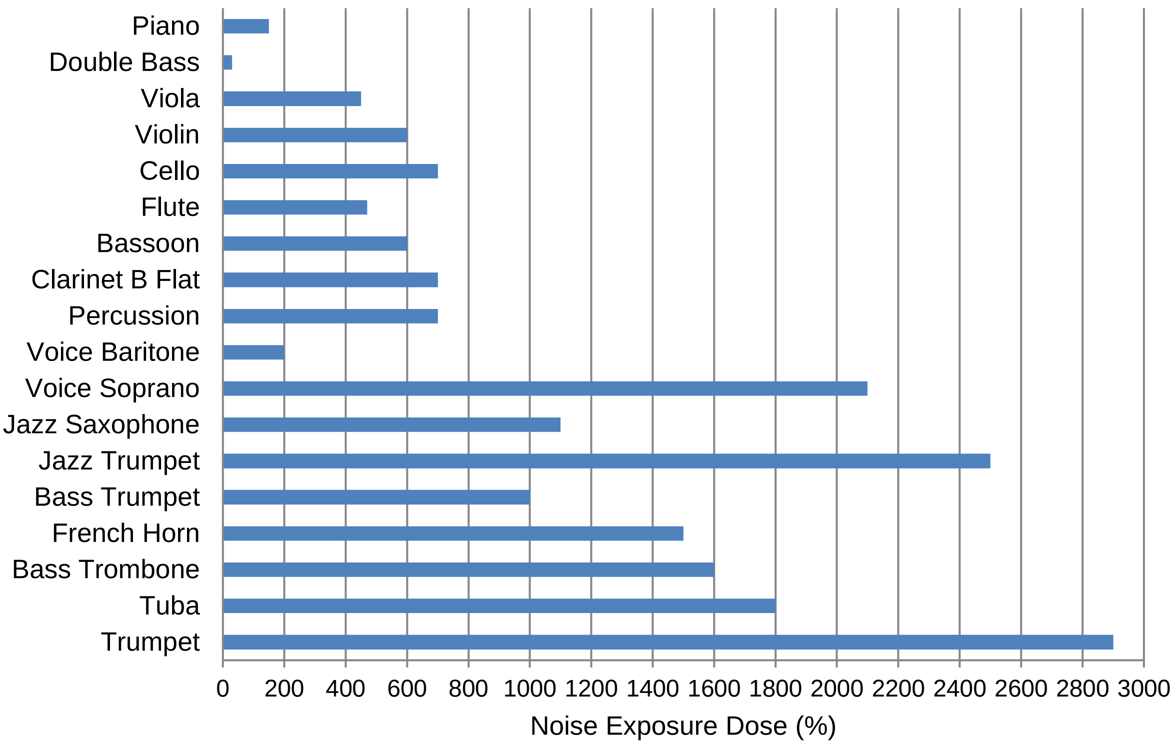


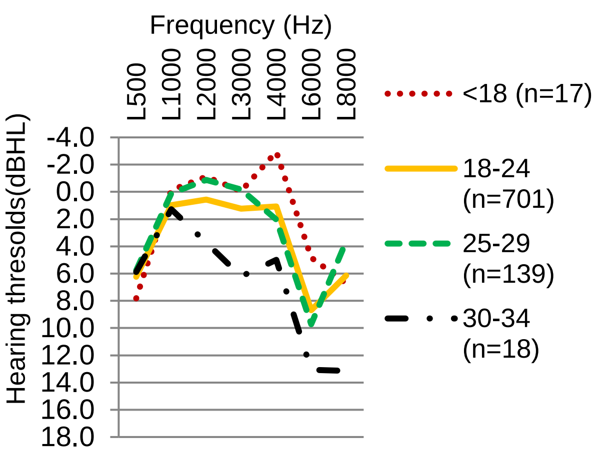
Figure 1. Sound exposure dose of 18 classical music students.

From figure 1 it can be clearly seen that sound dose, a linear percentage number, was higher than the allowed limit as given in [1], 100% is equivalent to 8 hours of 85 dBA with an exchange rate of 3 dB. The performers with the highest sound exposure were the soprano, trumpeter, and brass player all over 2000% sound dose. This of course should show up in the hearing health surveillance study given the typical 12.7 years of prior music instrument playing, see Section D.

D. Key findings from Hearing Health Surveillance

Compulsory hearing health surveillance was undertaken by all new students between 2007-2023, except in 2020 due to COVID, n=5300. Exit testing was taken by sampling 10% of the final year undergraduate students. Calibrated automated screening audiometers (Amplivox CA850 Mark 4) were used with the student listening through Audiocup TDH49 headphones. The students had the procedure explained, stepped into the soundproof room [6] and went through familiarisation with the Bekesy test procedure. These tests have resulted in numerous findings with the highlights detailed below.

Early data, from the first 1931 students tested, indicated a consistent reduction in hearing acuity of musicians at 6 kHz [21], see figures 2 and 3. Whereas a change in the hearing thresholds at 4 kHz is normally seen in cases of noise induce hearing loss [2], although a recent music (amplified) study of players also found a 6 kHz notch, n=84 [22].



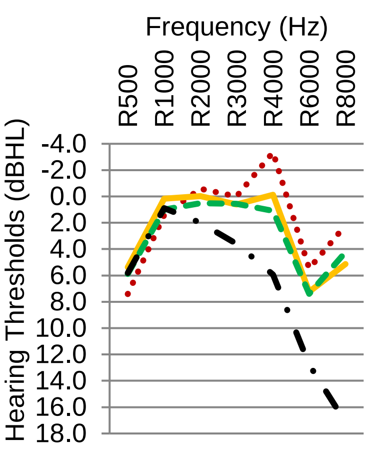


Figure 2. Hearing thresholds (dBHL) for males, n=875 classical music students by age group (left and right ears).

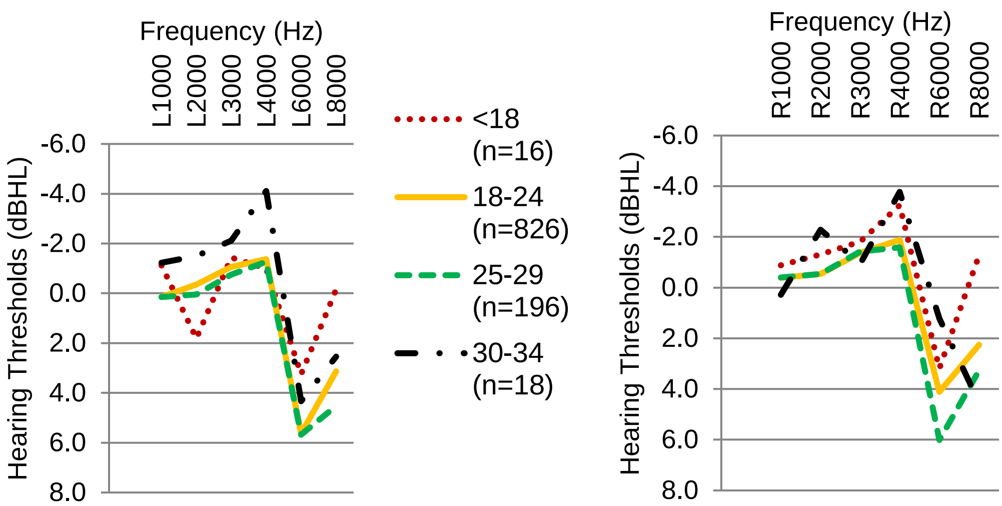


Figure 3. Hearing thresholds (dBHL) for females, n=1056 classical music students by age group (left and right ears).

The study also found that, based on the UK Health and Safety Executive (HSE) categorisation scheme [1] where pure-tone audiometry is seen as the 'Gold' standard, 94% of students had "Normal" hearing (acceptable hearing ability), 4.5% presented "Warning" levels of hearing loss (mild hearing impairment) and 1.5% "Referral" levels of hearing (poor hearing) [21]. Note that according to the HSE categorisation scheme, 75% of population for each age band and gender would have hearing within normal limits, 20% would normally present with a mild hearing impairment and 5% would need to be referred for further investigation. Again, confirming that students of classical music have excellent hearing.

In 2017 a review of the audiometric dataset pulled out a comparison of Piano Accompanists, n=70 and Pianists, n=302 [22]. It should be noted that primarily Piano Accompanists accompany Vocalists, normally in a small music practice room with a volume typically 30-50m^3. This demonstrated that the left ear of Piano Accompanists had identical hearing acuity as the Pianists. However, the right ear had a significant reduction in hearing acuity for the accompanists specifically at 6 kHz, on average a 3 dBHL change in hearing threshold in less than two years of playing, see figure 4.

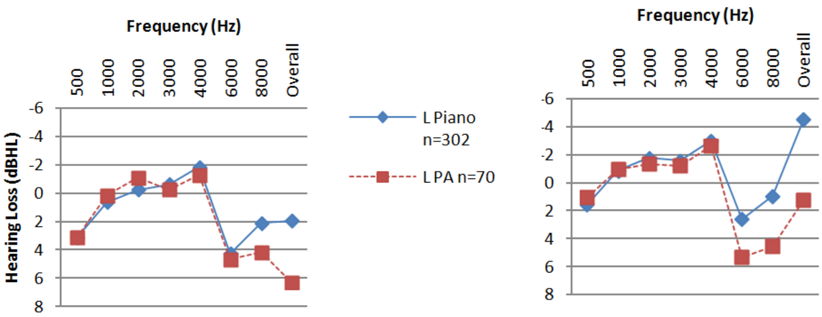


Figure 4. Hearing threshold of Pianists (—), n=302, compared to Piano Accompanists(----), n=70 (left/right ears)

The Vocalists were found to have symmetric hearing thresholds, as did the Pianists, see figure 5 for female Vocalists n=170 and Pianists n=196. This demonstrated that in a relatively short time, less than 2 years, the Piano Accompanists were exposed to high sound levels [20] which resulted in a reduction in hearing thresholds but did not affect the Vocalist’s acuity.

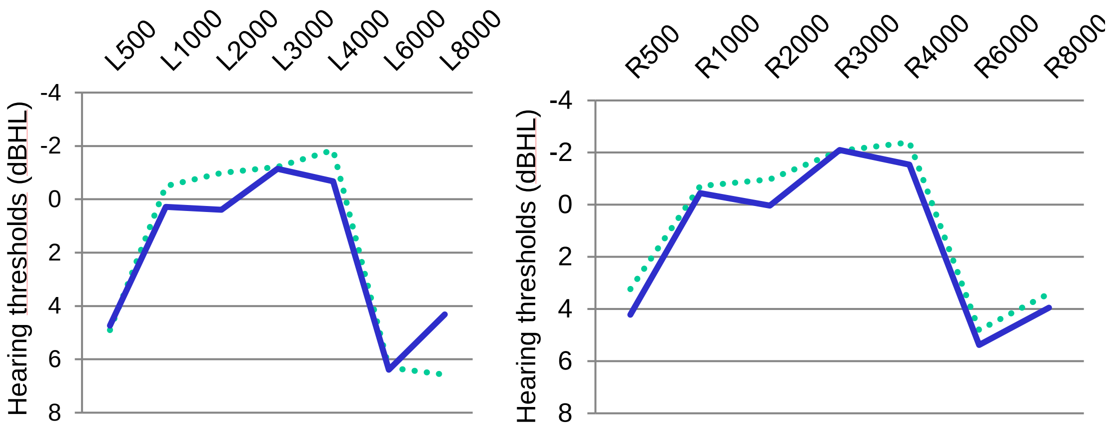


Figure 5. Averaged hearing thresholds (dBHL) for female Vocalists, n=170 (···) and Pianists n=196 (···).

It should be noted, based on the questionnaire results [20], that vocalists sing for less than one hour a day, whereas pianists practice 6-8 hours a day and piano accompanists accompany for 4 hours a day. The vocalist do however listen to other vocalists during the working day. Due to the layout of the piano the vocalist always stands to the right of the accompanist. Hence, possible explanations for these results are the right ear of the accompanist is more exposed and thus more at risk from excessive sound exposure; or music and noise do not have the same effect on physiology.

Exploring explanation one: the left ear could be acoustically shielded by the skull for higher frequency sounds, above 1500 Hz, and hence the right ear had a greater exposure. Trained vocalists produce the 3rd formant which is above 2000 Hz [24] allowing them to be particularly loud, greater than 100 dBA, see figure 1. Exploring explanation two needs a definition for music. Assuming it is what is self-produced and designed to be music then it is clear that each vocalist is producing music, and the accompanist is producing music. However, to each other that could be considered noise. This would be consistent with the common complaint from orchestral musicians that the problem is the people sitting behind them, not their own section. However, the orchestral layout is designed so that the section behind is louder. The result would be stress which reduces blood flow to the ear and hence a higher prevalence to hearing damage. Or a combination of the two explanations. Future study using binaural in-ear dosimetry is required to establish their sound exposure.

From 2011 onward every year approximately 10% of students, n=30, have been retested usually after a 3.7 year interval – the duration of their undergraduate studies. In the 2017 study results for 229 students were analysed as regards test-retests. When analysed by instrument group , n>20, for both ears across 1000, 2000, 3000, 4000 and 6000 Hz an improvement in the student cohort hearing thresholds was found. The improvement lessened for the instrument groups regularly exposed to higher levels of sound, e.g. Brass and Jazz students [25], see figure 6.

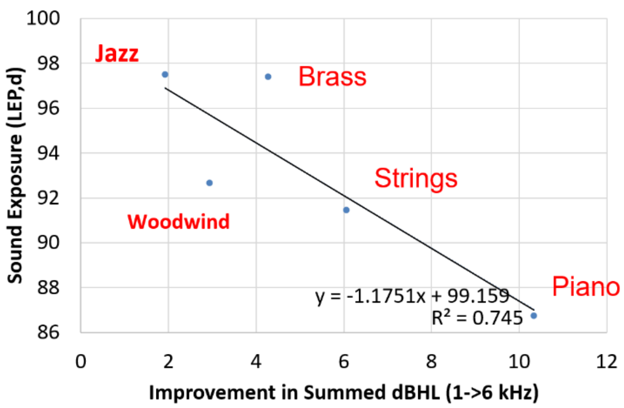


Figure 6. Comparison of test-retest summed hearing thresholds to sound exposure level by instrument group.

The results shown in figure 6 are counter-intuitive given they do not naturally follow the dosimetry data, see figure 1. There should have been a significant increase in hearing thresholds based on the measured sound dose according to ISO 1999 [5]. It should be noted that technology, environment and procedure were identical for both tests. A possible explanation for this unusual result is that audiometry is effectively a listening test and the musicians have developed listening skills over the course of their studies allowing them to perfect ensemble playing. Hence, classical music students could simply be better at detecting patterns of pure tones in the Bekesy test than the general population of the same age. The consequence is the need for a supplementary objective hearing test methodology, such as otoacoustic emissions, as suggested by Lutman *et al* [4].

E. Key Finding in Awareness

Normal hearing for 18-25 year old is defined as a 0 dBHL hearing threshold in ISO 1999 [5], for 50% of the population. As such, the students summed hearing losses, should be zero for 50% of the population. Analysis of the test data from 5300 students broken down into yearly cohorts of approximately 330 students has been undertaken. This allowed the authors to track the relative effectiveness of the on-going 17 year awareness campaign amongst classical music students, see figure 7.

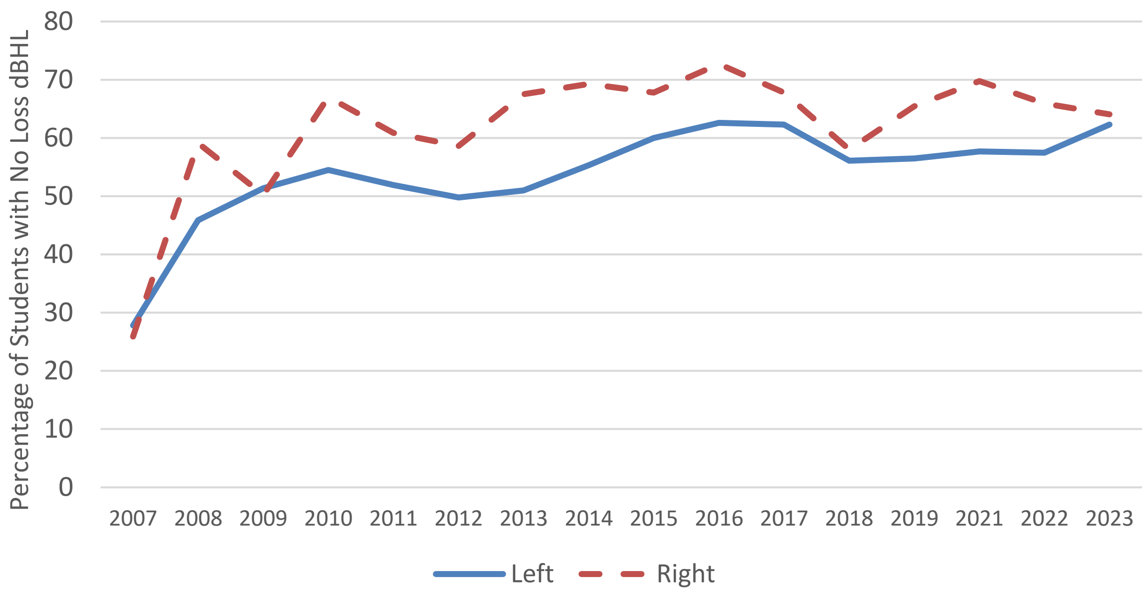


Figure 7. Annual cohort percentage with zero or negative hearing thresholds for left and right ears (dBHL).

As can be seen from figure 7 that after the first year of the programme the 50% threshold has been consistently exceeded. Currently, in 2023, it sits at 62% of the students with an overall zero or negative hearing loss (dBHL), an approximate annual increase of one percentage point. It should also be noted that across the years the right ear had consistently greater hearing acuity. This has also been found in a study by Fearn [26]. It should also be noted that in the RAM study the right ear was the second ear tested, whilst traditionally the right ear is the first ear to be tested.

IV. CONCLUSIONS

In 2008 O'Brian *et al* concluded that the nature of orchestral music was complex [2]. It is hoped that the past 17 years of research has taken the subject of music and acoustics forward by working together to understand the issues and find solutions. This also explains why it took the assistance of four PhD students, see acknowledgements, to start to address the problems and challenges set out in the original Face the Music project.

Results have found that classical music students have excellent hearing, 62% of the current cohort with negative or zero hearing thresholds. Strong evidence suggests that the students have been listening to the advice that there is a risk associated with excessive sound exposure which has been reinforced by the recent WHO Make Listening Safe campaign [27] and World Hearing Day, 3rd March.

Music appears to have a different physiological effect on hearing than noise, a predominant 6 kHz change in hearing threshold has been found rather than the 4 kHz associated with noise induced hearing loss due to excessive sound exposure. Based on the Pianist vs Piano Accompanist study Music Exposure might be a better term than Noise Exposure for the work undertaken by Classical Musicians, and subsequently Music Induced Hearing Loss would also be a better term than Noise Induced Hearing Loss.

Technological developments have provided the means to implement awareness raising tools which have become highly popular. Smartphones now include free and helpful built-in apps to provide the user with the tools to better understand their sound environment and alert them to the associated risks. Of course, these developments have also introduced a highly prevalent sound source, wireless headphone/earphones and new forms of entertainment e.g. competitive gaming.

The future of this study is to continue cross-sectional audiometry and supplement with a more objective hearing health surveillance methodology such as otoacoustic emission, a pilot study of which is on-going [28], as recommended by Lutman *et al* [4]. The study would also be greatly improved by follow up audiometry testing of the alumni to create a longitundal dataset that could be further analysed. Advances in room acoustics and materials could help mitigate the sound exposure of musicians using metadiffusers in orchestra pits [29-30] and sound absorbing mirrors in music practice rooms [31].

There is more work to do, and the mission was to complete the research programme within one generation (20 years). Musicians are the most talented people, and they deserve to have a better and safer working environment so that music can be enjoyed by all.

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AUTHOR DECLARATIONS

Conflict of Interest

The authors have no conflicts of interest to disclose.

Data Availability

The data that supports the findings of this study is not available being the property of the Royal Academy of Music.

Ethical Approval

Ethical approval was gained for the recruitment and participation of students, UREC 1248.

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