Institution: London South Bank University

Unit of Assessment: 13 - Architecture, Built Environment and Planning

Title of case study: Acoustics for the benefit of musicians

Period when the underpinning research was undertaken: 2000 – 2020

Details of staff conducting the underpinning research from the submitting unit:

Name(s):	**Role(s) (e.g. job title)**:	**Period(s) employed by submitting HEI**:
Professor Stephen Dance	Professor of Acoustics	January 2000 – present
Professor Bridget Shield	Professor of Acoustics	January 2000 – May 2014

Period when the claimed impact occurred: August 2013 – December 2020

Is this case study continued from a case study submitted in 2014? N

1. Summary of the impact (indicative maximum 100 words)

The introduction of the *Control of Noise at Work* Regulations 2005 meant that musicians working conditions were no longer judged to be healthy and so changes were needed. Professor Dance's research has permitted choristers at St Paul's, the opera singers at the Royal Opera House, 2,800 students at the Royal Academy of Music, and Henry Wood Hall to maintain their traditions and artistic integrity while complying with noise regulation, as well as ensuring the wellbeing of the musicians and music students. The designs produced have saved the Royal Opera House GBP1,000,000+ (£1m+) and Henry Wood Hall GBP250,000 (£0.25m) in refurbishment costs.

2. Underpinning research (indicative maximum 500 words)

The Acoustics Group at London South Bank University (LSBU) has worked with the classical music industry for the past 14 years. The driver for this was the introduction of the new *Control of Noise at Work* Regulations in 2005, which considered all sound to be noise, no matter what the source. These regulations reduced the noise exposure limits to levels, to 85 dBA or 87 dBA over a 40-hour working week, which impacted classical music with typical sound levels of 90 dBA. Classical music could be considered non-compliant due to the change in regulations. The research undertaken has allowed the exceptional standards of classical musicians to be maintained ensuring future generations' musical enjoyment.

The initial key insight used to inform the impact derived from EPSRC-funded research (GR/L20894/01), on which Professor Dance was a Named Research Fellow and Professor Shield was the Principal Investigator. In 2000 this research produced geometrical acoustics-based computer simulation software to model complex enclosed spaces. This software could accurately predict the sound field in rooms with wall-fixed panels of acoustic treatment **[R1]** which can reduce local sound levels significantly.

Further findings resulted from an AHRC-supported Knowledge Transfer Partnership with Sound Research Laboratories. Firstly, a new measurement methodology was developed to understand the noise dose that the musicians were exposed over their non-standard working day **[R2]**. Secondly, to understand the effect of music exposure on hearing, which is known to be complicated, a longitudinal study was sanctioned by the Royal Academy of Music. Starting in 2007, every new student to the Academy has undergone a compulsory standard pure tone audiometric hearing test at LSBU.

In 2009 an Emerald Grant funded the design, development and testing of a new acoustic treatment in the form of a sound-absorbing mirror **[R3]**. The sound-absorbing mirror was constructed from silvered, Myler-covered mineral wool fitted into a wooden frame. Three perfectly reflecting sound absorbing mirror prototypes were acoustically tested in the LSBU reverberation chamber. The results demonstrated that high frequency sound was reflected whilst low frequency sound penetrated to the mineral wool allowing that sound to be absorbed.

In 2010-11 the issue of a lack of personal sound dosimeters suitable for use by musicians was addressed. The existing dosimeters being designed for use in heavy industry type applications requiring a robust design and an 8-hour working battery life. Professor Dance worked with Audio[3]

to develop the first prototype: a small, lightweight, user-friendly sound dosimeter with a 24-hour battery life to monitor noise exposure **[R2, R4]**.

In 2018 research was undertaken to establish the acoustic characteristics of inflatables (airbeds), in particular their low frequency absorption. Inflatables have many advantages over traditional membrane-type absorbers such as cost, weight, and the lack of a need for structural fixing. Measurements were undertaken of multiple airbeds in the LSBU reverberation chamber to characterise their sound absorption coefficient **[R5]**. It was found that as the depth of the airbed increased the broadness of the absorption increased, thus a double airbed was actually an excellent low-mid frequency sound absorber.

A collaboration was formed with the Universities of Le Mans and Valencia in 2018 to develop a metamaterial that could act as a metadiffusing panel. In 2017 it was found by the University of Le Mans that specific structures could create thermoacoustic viscous boundary losses that would slow the speed of sound. Using mathematical modelling, optimised thin structures were created at LSBU that were only 1/14th the thickness of traditional sound diffuser designs whilst providing identical acoustic performance. LSBU built the world's first metadiffuser using 3-D printing technology. This panel was independently tested under laboratory conditions at the University of Le Mans, where it was found to perform exactly as predicted across two octave band frequencies **[R6]**.

3. References to the research (indicative maximum of six references)

References [R1], [R2], [R5] and [R6] are in peer-reviewed journals. [R4] is a peer-reviewed conference contribution. Professor Dance was awarded the Institute of Acoustics Tyndall Medal (2014) for the program of research in [R2]. [R5] and [R6] are submitted as outputs for REF2021 in UoA 13.

[R1] S. Dance, B. Shield. The modelling of sound fields in enclosed spaces with absorbent room surfaces. Part II- Absorbent Panels, Applied Acoustics, 61(4), 373-384, 2000 doi.org/10.1016/S0003-682X(00)00011-6

[R2] S. Dance*, G. Zepidou, Sound exposure of choristers, noise and health, 21(98), 2019 DOI: https://doi.org/10.4103/nah.NAH_40_19

[R3] S. Dance*, R. Lorenzetto. A new type of absorber for use by classical musicians in rehearsal room, Proc. Euronoise, 2009, Edinburgh

[R4] S. Dance, B. Backus, E. Bukhary. Novel personal noise dosimeters, Proc 11th International Congress on the Noise as a Public Health Problem (ICBEN), London 2011

[R5] D. Shearer, S. Dance*, L Gomez-Agustina, J. Randall, Flexible control of acoustic conditions in a music rehearsal space using airbeds, Applied Acoustics, 173, 2021, doi.org/10.1016/j.apacoust.2020.107708 (note: first available online October 2020).

[R6] E. Ballestero*, N. Jiménez, J-P. Groby, S. Dance, H. Aygun, and V. Romero-García Experimental validation of deep-subwavelength diffusion by acoustic Metadiffusers, Applied Physical Letters, 115, 2019 DOI: https://doi.org/10.1063/1.5114877.

Grants relevant to the underpinning research

All grants were peer-reviewed

Knowledge Transfer Partnership with SRL (2007-10) funded by AHRC £190,000.

EPSRC Grant GR/L20894/01, Development of a Model for the simultaneous prediction of internal and external sound fields, 1996-99. Final report submitted January 2020 £125,000.

Emerald Grant fund 2009 £10,000.

4. Details of the impact (indicative maximum 750 words)

In Europe there are currently more than 170,000 individuals involved in classical music, of whom 30,000 are members of the Music Union. There are 20,000 professional classical musicians performing in 480 orchestras across Europe. In the UK, 31 out of 43 of London's theatres staged musicals, with musical theatre now contributing £400 million per year to London's economy. The research of Professor Dance has saved venues over GBP1,200,000 (£1.2m) and helped protect the hearing of 3,000 highly trained musicians over the REF period.

Professor Dance's research has had a significant impact on musicians and music venues in the UK, resulting in a change of education practice and policy, the formation of committees, the use of a new dosimeter, creation of datasets, and the development of novel acoustic treatments. When

the Control of Noise at Work Regulations 2005 were introduced, the main contention for music organisations was that music was to be treated as noise, whereas noise was traditionally seen as a side effect of work, rather than the point of work. The Concert Events Manager at the Royal Academy of Music says, *"As an educational institution we looked at how best to educate our students in the risks associated with noise levels and how to protect their health for a future career in music. You cannot make music without making noise and it has been very challenging for the music industry whose main product is sound to meet the legal requirements which apply to all places of work."* **[S1].**

Formation of noise management committees

Leading organisations in the field of classical music approached LSBU due to its knowledge of acoustics to assist with the issues arising from the introduction of the new regulations. On the advice of Professor Dance, new committees were formed to steer the direction of the research to address specific challenges of each organisation were created **[S1, S2, S3]**. This was first instigated by the Royal Academy of Music in 2007, then in 2008 at the BBC, and 2009 by the LPO. In 2017 the Royal Opera House started their Sound and Performance Study Group to address pressing issues **[S4, S5]**.

Educational Awareness, Protection and Policy

Professor Dance has created musician-focused research-informed materials to educate classical musicians on the risks of excessive sound exposure **[S1]**. Instrument-focused materials have been presented to all new Royal Academy of Music students (2,800 students, 2013-20) usually held during Induction week. The Concert Events Manager at the Royal Academy of Music said, *"A seminar is given to all new students each year educating them on the balance between music, hearing and acoustics both inside and outside the Academy."* **[S1]**. A change in attitude was instigated at the Royal Academy of Music, with specialist hearing protection and musicians' earplugs issued to each student (1,750 pairs, 2016-20) **[S1]** . The Concert Events Manager at the Royal Academy of Music stated, *"Students are now each issued musician earplugs, although some musicians, for instance brass or vocalists, have difficulty in using them. We have tested various earplug designs and now the brass are issued specialist vented earplugs which we have found allow them to perform."* **[S1]**. Versions of these educational materials have been presented to the London Philharmonic Orchestra in 2015, BBC Singers in 2018, the choristers of St Paul's Cathedral in 2019 **[S3]**, and the Royal Opera House in 2020.

At the Royal Academy of Music, and the Music Department of St Paul's Cathedral, policy decisions were directly affected by the educational materials produced. Programming and room allocation were the first changes to be implemented. The Royal Academy of Music stated, "*LSBU has gone on to measure all of our different types of rooms and instruments/voices to create baseline data, which did not previously exist. This was used to inform the timetabling of practice and rehearsals to inform us of the likely noise exposure levels*." **[S1]**. These changes were designed to minimise sound exposure of the students and choristers **[R2]**.

At the Academy students used larger rehearsal rooms and the Music Professors mixed the repertoire (lighter and heavier pieces) to balance the noise exposure over the course of a year, starting in 2008 **[S1]**. For the choristers, a new all girls' choir was planned to commence in the summer of 2020 to rebalance the sound exposure experienced by the boys. The Deputy Music Director said, "*We have also reviewed and will introduce a girls' choirs. This will be in the summer 2020 but, due to COVID-19, it is likely to be put back several years. That said, the decision has been made*." **[S3]**. The repertoire changes were also taken up and implemented by the London Philharmonic Orchestra, 2010-2014. In 2014 a new Artistic Director was employed who had not attended the educational seminars.

New commercial dosimeter for sound monitoring

Taking forward the research knowledge gained in assessing sound exposure of classical musicians **[R4]** a new product was produced: the Audio^3 *SoundBadge* **[S6]**. The CEO of Audio^3 reminisced, *"I was then working with the Royal College of Music and Stephen Dance was undertaking similar projects with The Royal Academy of Music. We shared knowledge about the*

need for a SoundBadge, specifically for musicians. There were other products in the market, but they were not designed or applicable for musicians, typically for factory workers, which was not what was required for this particular sector." **[S6]**. Audio[3] produced a discrete, light-weight, rechargeable, long-lasting dosimeter for which Professor Dance undertook the testing to ensure compliance with the international standard IEC 61252. He then went on to undertake field trials of the prototypes for robustness and interface design. The SoundBadge was made commercially available in 2013, being sold in the UK by Campbell Associates and internationally by Audio[3]. To date the initial 250 devices have been sold generating GBP125,000 (£125k) **[S6]**. SoundBadges have been used to measure sound exposure at the Royal Academy of Music [**S1**], Royal Opera House [**S2**], and at St Paul's Cathedral **[S3]**.

New dataset on hearing acuity of classical musicians

A compulsory screening hearing test has resulted in the creation of a Royal Academy of Music database of all 2,800 students in the review period (2013-20). This has produced the largest audiometric study of classical musicians in the world: 4,500 students **[S1]**. This database has been used to produce educational materials tailored to each instrument group **[S1]**. This study has informed new guidance **[S7]**.

The second impact, driven by analysis of the database, is that pure tone audiometry - is no longer seen as the 'Gold Standard' method to establish hearing acuity, the Royal Academy of Music adding, *"We tested some 350 students per year. The study took four years to provide the first lot of evidence. Due to the length of tuition (over four years for undergraduates), the data showed that their hearing actually improved although the louder the instrument, the lower the improvement."* **[S1]**. This result led in 2020 to new technology being applied to test the inner ear's performance, previously only used to test new-born babies. *"We are also introducing a new test – a three-minute test where the subject cannot anticipate. This will result in a three-year pilot study on otoacoustic emissions,"* said the Concert Events Manager at the Royal Academy of Music **[S1]**.

Novel acoustic treatments

The Royal Academy of Music audiometric survey found that music students spent long hours practising **[S1]**. A new approach to reduce their sound exposure was needed that did not affect the quality of the practice. The research in **[R3]** resulted in sound-absorbing mirrors being installed in four music practice rooms at the Royal Academy of Music, 2010-14 **[S1]**. The location of the mirrors in the rooms was optimised using the mathematics described in **[R1]**. The mirrors were found not to absorb high frequency sound, or "attack" of the instrument, but they still effectively removed the low frequency sound reducing the sound exposure of students by up to 2.5 dBA compared to traditional glass mirrors. This nearly doubled the safe length of time the musicians could practise whilst not affecting the acoustic or the value of the practice. In total 700 students in 2013-14 have benefited from practising in the music practice rooms without realising they were acoustically treated.

Henry Wood Hall (HWH) wanted to improve the acoustics of their large rehearsal space as the boominess of the hall preventing them from hiring out the venue for smaller scale rehearsals. The manager of the hall went on to say, "*Originally, management considered improving the acoustics and received quotes from professionals. Whilst this was 15 years ago, the quotation was circa £250,000. The charitable organisation could not afford it and there was no evidence to suggest that even the acoustics would be improved with the investment"* **[S8]**. This was unaffordable and required 120 wooden resonators to be installed in the venue so HWH approached Professor Dance for an alternative solution. In 2018 thirty airbeds were installed at a cost of GBP1,500 in Henry Wood Hall based on the research findings from **[R5]**. The airbeds were optimally positioned in the hall using mathematics given in **[R1]**. This inexpensive, quick to deploy, lightweight, and flexible solution improved the acoustics of the hall benefiting the musicians and conductors. *"Following the installation of the beds, [a renowned conductor], said: 'There is a marked difference in the sound quality of the room. For the first time, there are no balancing issues.'"* said the Manager of Henry Wood Hall.

In 2017 the sound levels in the orchestra pit at the Royal Opera House were found to be too high **[S4, S5]**. An acoustic consultancy had been approached which had proposed an unacceptable solution. "*A feasibility study was undertaken by a leading external consultancy which recommended removing the first six rows of seating and expanding the orchestra pit. This was dismissed as unviable as the Opera House would need to shut for 6 months, there would be a long-term loss of revenue, the cost was estimated at £1 million+ [GBP1,000,000+], the predicted noise exposure reduction was minimal at 1-2 dBA, and the ensemble playing conditions were at risk of being diminished",* stated the Human Resources Manager at the Royal Opera House **[S2]**.

In 2018 the Royal Opera House approached Professor Dance for a more practical solution to reducing the sound level in the pit without adversely affecting the quality of the performance. The main practical issue was the lack of space in the pit to implement a solution. Leading an international team Professor Dance developed new metamaterials which could be 3-D printed which allowed the sound to be redistributed or diffused, a metadiffusers, so the sound could no longer building up in the pit based on the mathematics in **[R1]**. The metadiffuser's advantage being it is only 1/14th of the thickness of any existing solution and performs identically **[R6]**. This solution has the added benefit of allowing the sound to escape into the auditorium where it can be fully enjoyed. The Royal Opera House will implement this solution once restrictions due to COVID-19 are removed: "*We have taken the decision to go ahead with lining our pit with this new panel. However, due to COVID-9, the research has been delayed… Alongside that, people in Performing Arts have not been able to perform due to COVID-19 Restrictions*", explained the Royal Opera House **[S2]**.

5. Sources to corroborate the impact (indicative maximum of 10 references)

[S1] Testimonial, Concert Events Manager, Royal Academy of Music
[S2] Testimonial, Human Resources Manager, Royal Opera House
[S3] Testimonial, Deputy Music Director, St Paul's Cathedral
[S4] https://www.judiciary.uk/wp-content/uploads/2018/03/goldscheider-v-roh-judgmentL.pdf (accessed 9th February 2021)
[S5] https://www.judiciary.uk/wp-content/uploads/2019/04/goldscheider-v-roh-judgment.pdf (accessed 9th February 2021]
[S6] Testimonial, Chief Executive Officer, Audio^{3}
[S7] Hearing Conservation for Performers: Best Practice Guidance, British Association for Performance Arts Medicine, 2020
[S8] Testimonial, Manager, Henry Wood Hall