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Noise at Work Regulations 2005 and the Royal Academy of Music 'Noise Project'

Georgia Zepidou (1), Stephen Dance (2)

(1) Sound Research Laboratories Ltd, 70 Cowcross Street, London, EC1M 6EJ, UK
(2) Acoustics Group, FESBE, London South Bank University, London, SE1 0AA, UK

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ABSTRACT

With the introduction of Control of Noise at Work Regulations in 2005, entertainment noise was given a temporary exemption until 2008. Unfortunately classical music was caught by the legislation, even though it is the point of the activity rather than a side effect, as is the case for industrial noise. Since 2007, the Royal Academy of Music (RAM), as a leading conservatoire, has been working together with London South Bank University on developing all practical means of complying with the new regulations. The 'noise project', assisted by the full cooperation of the Academy management, administrators, professors and students, can be split into four separate challenges: (1) educating the musicians (both students and teachers); (2) assessing the aural history of the musicians (students and teachers) and monitoring any changes in terms of hearing loss; (3) assessment of individuals noise exposure and identification of key instruments/ensembles/environments in the Academy that create the highest noise levels and (4) development of mitigating solutions (architectural, teaching, novel solutions). The emphasis of the project was to only to use or apply culturally acceptable methods and solutions. This was to maintain the exceptional standards held by the Academy. This paper discusses the Royal Academy of Music 'noise project' and all steps taken so far towards both musicians' awareness and protection from excessive noise exposure, but also towards compliance with the new regulations.

INTRODUCTION

The Acoustics Group of London South Bank University and the Royal Academy of Music formed a partnership to address the issues raised by the new Control of Noise at Work Regulations 2005 [1]. Over the past three years this pioneering collaboration has resulted in the Academy setting the standard by which classical music organisations are assessed.

The over-riding concern of the noise team, formed for this purpose, was that the quality of performance and artistic planning would be unaffected by any solutions offered. To this end individual practice and rehearsals were used as test beds for the solutions developed. The results of these experiments were reported to the noise team, and included noise exposure, room assessments, layout arrangements, audiometry, and noise control solutions. In addition, educational seminars were introduced to the Freshers week programme (week 0).

THE 'NOISE PROJECT'

The Royal Academy of Music noise project consists of 4 main elements. The form of this compliance action plan was discussed and decided by the noise team after a preliminary dosimetry, which allowed the degree of the challenge that lay before the team to be fully gauged. The team now hold nine minuted monthly meetings per academic year to discuss progress and undertake short term planning.

Education

The industry has published educational material and guidance which addresses the issue of noise: 'Sound Advice: Control of noise at work in music and entertainment' [2] and 'A Sound Ear II. The control of noise at work regulations 2005 and their impact on orchestras' [3]. These two documents provide information on the dangers associated with musicians' noise exposure, and give general guidance on how to assess and control/reduce noise exposure.

In addition to the above, the noise team decided to engage a different approach to the issue of educating the Academy's students by introducing seminars per instrument group during Freshers' week. The advice offered by the Acoustics Group during the 1hr seminars is more specific and is based on the knowledge gained as to the issues of direct concern, see figure 1.

Source: (Zepidou, 2009)
Figure 1. Educational Seminars at RAM

Audiometry

As part of the Academy's health surveillance plan, it has been decided that all 1st year students must undergo audiometric testing during their induction at Freshers' week. Since 2007, each student underwent an automated audiometric screening test done in an environmental chamber; see figure 2. The test was based on a pure-tone air conduction Bekesy test. One-to-one interviews with each student were used to identify any factors, which may influence the health surveillance results.

Source: (Zepidou, 2007)
Figure 2. Environmental chamber with double layer doors and Amplivox audiometric equipment

As a result of the testing over the past three years, an audiometric database has developed, holding almost 1000 student audiograms. By categorising the audiometric data, based on the new regulations categorization scheme, it was established that 94% of the Academy students have what is considered to be good hearing. This also means that 1.5% of students had referral levels of hearing loss. The remaining 4.5% of students had warning levels of loss. For the general population these percentages are set at 5% and 20% respectively, indicating that young musicians have excellent hearing [4]. However, noise induced hearing loss has a dose-response relationship, and hence may take up to 20 years to become apparent amongst classical musicians.

Results also indicated that female students tested have better hearing than male. The incidence of males in the warning category is twice that of the females for both ears. Generally, incidence of warning and referral levels was higher in the right ear than the left for both men and women.

Highest percentages of warning/referral levels were calculated for the string instruments, see table 1. When comparing right and left ear percentages within the strings, it is easily identified that the string players' left ears had higher hearing loss than the right. This is expected, as the most popular string instruments are asymmetric (violin/viola) with the noise being emitted at a very short distance to the left ear. Respectively, 50% of the total referral levels for all instruments in the left ear were found amongst string players with 19% referrals for the right ear. Second largest incidence of warning and referral levels was found amongst brass players being followed by pianists and singers.

When, however, comparing incidence of warning/referral levels within each instrument group, results show that the worst case was that of the brass group being followed by the percussion/timpani group (left ear). Lower incidences were found amongst musical theatre singers, despite having noise levels measured during rehearsals of around 90 dB(A).

Table 1. Hearing categories within instrument group

	LEFT EAR			RIGHT EAR		
	Acceptable %	Warning %	Referral %	Acceptable %	Warning %	Referral %
Brass (77)	87.0	11.7	1.3	87.8	13.0	5.2
Piano (165)	96.4	3.0	0.6	94.5	4.2	1.2
Musical Theatre (98)	96.9	2.0	1.0	96.9	3.1	0.0
Strings (250)	92.4	4.8	2.4	93.6	4.8	1.6
Voice (133)	94.7	3.8	0.8	93.2	3.8	2.3
Woodwind (91)	96.7	3.3	0.0	93.4	4.4	2.2
Percussion/Timpani (22)	86.4	9.1	4.5	95.5	0.0	4.5

Source: (Zepidou, 2010)

When comparing averaged hearing loss per frequency for each instrument group, a 6kHz dip, i.e., an increase in hearing loss at the 6kHz frequency when compared to the adjacent 4 and 8kHz frequencies, was found. This is a sign of noise induced hearing loss, which however has not been proven yet to be associated with musicians' noise exposure. Please note that headphones used were properly placed on musician's head and have no known artifacts that could have increased thresholds at 6kHz.

Noise exposure monitoring (dosimetry)

As part of the formal risk assessment at the Royal Academy of Music and after a preliminary noise monitoring done during the first months of the project, an extensive programme of detailed noise exposure measurements was done over the last 3 years. The knowledge gained has been used to identify those musicians most at risk and the rooms that are unsuitable for particular types of rehearsal, see figure 3.

Measurements were carried out using individual noise monitoring devices (Cirrus Research Ck:110A dosebadges) which were securely fixed to the clothing of the musician (as close as possible to ear level) without restricting the musicians' movements. The badges were switched off for the interval or rehearsal break in order to make an accurate assessment of the musicians' noise exposure from the music played. The noise exposure of the musicians was established over each session. The results are presented as an L_{Aeq}, for the duration of the rehearsal/concert. During each measurement, detailed notes on seating arrangements, existing absorption in the room, screens, dosebadge locations, etc were taken. Measurement locations were chosen to cover, where possible, not only the anticipated loudest locations but also a reasonably even spread. Background noise measurements were not included in the monitoring procedure, as noise levels inside the rooms were very low and therefore not contributing to the musician's noise exposure. Please note that, although both Sound Ear II and Sound advice, which both describe a formal noise monitoring procedure, were not available at the beginning of the monitoring, the actual methodology followed was very similar to the ones described in the two documents.

Source: (Zepidou, 2006)
Figure 3. Noise exposure measurements at RAM (Trombone Choir)

The noise exposure measurements have been gathered in to a large database covering both music students and professors. Measurements schedule covered:

- All different types of rooms used in the Academy for rehearsals and concerts.
- All different types of instruments, ensembles (chamber ensembles, brass band, etc) and music departments, such as jazz department, musical theatre, etc.
- All possible types of repertoire and instrumentation.

Results from the detailed noise monitoring revealed the extent of the noise exposure problem in the Academy. Noise exposure level of string players during a 3hrs rehearsal is usually below the upper action value of 85 dB(A) Lep,d in most rooms (unless very close and at the same floor level to a noisy instrument). However, noise exposure level of brass, wind (especially flute and piccolo players), timpani and conductors are most of the times above the noise exposure action limit of 87 dB(A). In addition, timpanists are most of the times found to exceed the limit of 140 dB(C) for impulsive noise.

The majority of the players reach or exceed the allowable, by the regulations, daily noise dose (100%) within the 2-3 hr rehearsal. As the study programme of the Academy is very intense, students are many times required to attend multiple rehearsals during the week or even day. At the same time, students also need to practice for the above rehearsals, their own instruments' lessons, competitions, etc. All mentioned activities (within the Academy) could easily lead to daily and weekly exposure levels that exceed the upper action values for most of the students.

Finally, analysis showed that the rehearsal room has a significant effect on the musicians' noise exposure, especially in the case of smaller ensembles. Noise levels measured in reverberant spaces or spaces with limited volume (as the theatre pit) were found much higher than those measured in other, more fit for purpose, rooms of the Academy.

Development of mitigating solutions

Excessive noise levels recorded during the vast majority of dosimetry measurements at the Royal Academy of Music indicated, even at early assessment stages, the urgent need for noise mitigating solutions. Over the past 3 years, numerous ways of protecting the students and staff of the Academy were investigated. These began with the education of all students and the effort of raising their awareness on the subject (on-going process), but also included investigations on:

- Existing room acoustic conditions of all teaching and rehearsing spaces.
- Feasible ways of improving existing room acoustic conditions in the above spaces (room treatments). Investigations were undertaken using acoustic modelling techniques.
- Feasible ways of mitigating the problem via management techniques. Amongst things considered and implemented were: reducing rehearsal time, appropriate use of each room, concerts/rehearsal planning, etc.
- The effectiveness of commercial noise control solutions available (screens, monitoring devices, etc).
- Development of novel noise control solutions suitable for each use/space.
- Existing and novel hearing protection suitable for each instrument.

Noise exposure measurements of large ensembles, where distance between musicians is very small, or where the rehearsing space is limited and additional room treatments would not be sufficient, indicated the need to focus on local solutions that control direct sound transmission between musicians (e.g. screens) as well as devices that indicate excessive noise levels within the room and raise the awareness of musicians.

Noise Monitoring

The Academy has purchased four noise alert monitors, the *SoundEar 'traffic light' system*, to educate the students as to their noise exposure levels, see figure 4. The SoundEar is a noise indicator that presents a clear warning as soon as the noise within a room exceeds a preset limit [5]. Four Sound Ear noise monitors were purchased for the Royal Academy of Music. These were positioned in four different types of room (Jazz room, 2 individual practice cells, and a teaching room). The SoundEar is also an integrating sound level meter, but has no display or calibration facility. The Ear has 8 lights, each light representing 1 hour of exposure. There are 3 signs that light up depending on the current overall sound level, dB(A). These can be either none, green, green/amber, amber, amber/red, red or flashing red.

Source: (SoundEar AS, 2008)
Figure 4. SoundEar 'traffic light' system.

A sign with information on how the 'traffic light' system works and what each color indication practically means to the rooms' users was hung next to each device. Noise control measures for each indication are recommended.

Although personal dosimeters are being used for the formal risk assessment at RAM, another solution was found in using Apple's *iPhone* as an integrating sound level meter. An application, 'SoundMeter' from Faber Acoustical, can be downloaded for a small fee from either Apple's iTunes store or the Faber Acoustical website [6]. The latest version of the software is capable of simultaneously measuring overall dB and dB(A) over a time period and peak noise of up to approximately 105 dB (un-weighted) using the iPhone's built-in microphone (iphone mic upper operating limit =105dB(A) .

Measurements using a 2G and 3G iPhone with the SoundMeter application were carried out in the university laboratory and at various locations at RAM (teaching rooms, main concert hall, theater, theater pit) and were always compared to a hand-held Class 1 integrating sound level meter or a Class 2 noise badge. Results have shown that the 3G iPhone is accurate to 1dB(A) with better frequency response than the 2G. The tiny microphone on both iPhones has been found to be incapable of accurately monitoring the sound produced by timpani instruments. Please note that, SoundMeter has not been shown to meet ANSI or IEC standards for sound level meters. Although it is not being used to collect noise data for the purpose of RAM's risk assessment, it is considered as an excellent indicator of excessive noise exposure during rehearsals, it is user friendly and its use contributes to the musicians' education and awareness.

Finally, a collaboration with audio3.co.uk [7] and the University College London (UCL) has resulted in a new personal noise meter, the *SoundBadge*, see figure 5. SoundBadge has been designed and built specifically to meet the needs of musicians. Traditionally acoustic instrumentation has been designed for use in industrial environments with the consequent increased costs of manufacture. The SoundBadge is much smaller and cheaper to purchase, whilst meeting the same international standards.

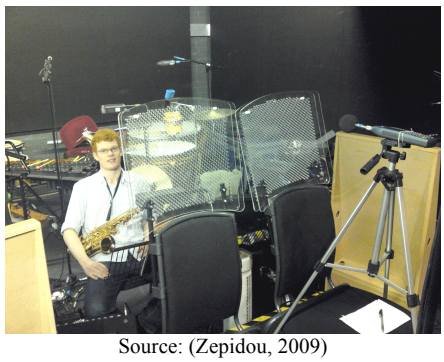
Source: (audio[3], 2010)
Figure 5. SoundBadge by Audio3

Novel Noise Control Solutions

Beyond the traditional room acoustic noise control measures for orchestras, theatres and music schools recommended in 'A sound ear II' and 'Sound advice', two novel solutions were investigated at the Royal Academy of Music – acoustic screens/shields and sound absorbing mirrors.

Acoustic Shields

The Royal Academy of Music purchased twenty-seven Amadeus clip on dual layer Perspex screens to be used in the main concert hall (Dukes Hall). These fit on top of Amadeus chairs, see figure 6.



Source: (Zepidou, 2009)
Figure 6. Amadeus acoustic shields.

According to the manufacturer, the shields are designed to create a void between two skins which traps and diffuses some of the unwanted mid to high frequencies that cause discomfort while at the same time there is no sound reflected back to those seated behind the shield.

The Amadeus shields were tested in the Academy's theatre pit and the main hall with the help of music students, mainly brass. Measurements in the pit indicated reductions of 0.2 – 4.6 dB(A) in overall noise level at the position of the musician (receiver) in front of the screen depending on the instrument used. Results from measurements in the main hall show reductions of 2.6 - 6.3 dB(A), with the highest reduction when using a trumpeter, which indicates the effectiveness of the Amadeus shields when positioned in front of an instrument with a 2 kHz dominant frequency, as the trumpet. Results at the players' position indicated a small increase in the noise exposure of the musician facing the shield (+1.1 dBA), which however is considered as unperceptible. The Amadeus shields were also measured during a full orchestra rehearsal in the main hall. Measurements with and without the screen showed maximum reductions of 0.6 dB(A). This was mainly due to the maximum height setting of the shields, which is not sufficient to protect the players' ears when the musicians are seated on risers.

Acoustic Screens

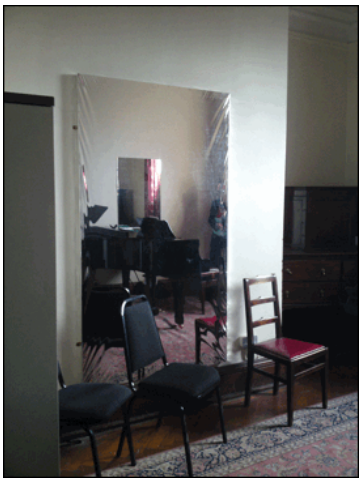
A new absorbent noise screen was developed for use specifically in orchestra pits. The new screen was tested both in the laboratory and in the Academy's theatre pit. Results from the anechoic chamber indicated the effectiveness of the screen above 500Hz. When tested in the pit, noise levels at the receiver position were found 2.6 – 3.3 dB(A) below those without the screen (consistent reduction). The new screen has proved to be effective, however as pit space is at a premium, a new design is currently under development. The new design, see figure 7, aims to have a zero footprint being mounted on to the music stand itself. Tests show that the new music stand screen in the main hall produced reductions of 4dB(A) with 1dB(A) increase at the players' position (reflected sound).

Source: (Dance, 2010)
Figure 7. New music stand screen

Sound Absorbing Mirror

London South Bank University developed an entirely new type of sound absorber, the sound absorbing mirror (patented July 2009). It is a novel solution that acts as both an effective absorbing panel and a mirror. As the majority of musicians spend long hours practicing in front of mirrors, the sound absorbing mirror can replace a traditional, highly reflective, mirror while at the same time absorb the unwanted frequencies of musical instruments reducing noise levels and subsequently noise exposure. The development of the sound absorbing mirror was based on a new lightweight reflective, heat shrunk and adhesive film that was proven to be acousti-

cally transparent. The film is laid and fixed to a wooden frame with 30mm thick dense mineral wool with a 3mm air gap between the film and the insulation. Laboratory testing results showed that the mirror is an effective absorber between 500-4000 Hz with a performance of 0.85 NRC.



Source: (Zepidou, 2009)

Figure 8. Sound absorbing mirror at the Royal Academy of Music.

The mirrors were installed at the Royal Academy of Music, see figure 8. The Academy decided that, due to a mirror's fragile nature, it would be best to use the mirrors in the teaching rooms, so that the students would be supervised at least some of the time. Noise exposure measurements have been undertaken at the Academy as to the reduction in noise levels. Subjectively, the musicians like the mirror as the "attack" of the instrument goes unabsorbed. Reductions in noise exposure of the order of 2.5 dBA for a flutist and 4.0 dBA for a trumpeter have been found. Reverberation time measurements showed a reduction of around 0.1 sec with the mirror in the room. This indicates that while the mirror is not reducing the reverberance, so preferred by the musicians, it still acts as an effective solution in reducing noise exposure. It must be mentioned that the effectiveness of the mirror depends on the instrument played (sound directivity changes for each instrument and frequency), the distance of the musician from the mirror and the positioning of the musician (and instrument) in front of the mirror (angle of incidence).

Hearing protection

The knowledge gained from noise exposure measurements done during the past 3 years has been used to identify those musicians most at risk and the rooms, which are unsuitable for particular types of rehearsal. As an immediate solution, the Academy has organised, through a company offering hearing protection solutions, a discount on custom fitted musicians earplugs. Those students identified as at risk are advised to use the earplugs only for individual practice and rehearsals. Information on all available types of hearing protection and the best option for each instrument group is given during the educational seminars and the audiometric testing at the beginning of the year. Information is also available at the Academy's intranet. It must be noted that the Concerts Administration office freely provides disposable industrial earplugs.

CONCLUSIONS

Since 2006, the Royal Academy of Music and London South Bank University have been working closely to address the issues raised by the new Control of Noise Regulations 2005. An extensive noise project comprising audiometry, education, dosimetry and investigations on all available and novel mitigating solutions has put the Academy at the forefront in addressing the noise issue, setting the standard by which classical music organisations are assessed.

For the next phase of the noise project the mutual partnership aims to work towards addressing specific problems that have been identified. The first is to provide protection for the musicians without the need to resort to earplugs. This could be achieved using acoustic screens, but as space at the Academy is at a premium, zero-footprint designs will need to be developed. The second is to challenge the regulations as to the noise levels specified currently, as these were based on broadband random noise rather than music. By building a database of hearing acuity and continuing the dosimetry, a comprehensive case can be made. This would allow the regulations to be reset to those of the previous noise directive [8], which were more relevant for classical musicians in terms of noise exposure levels. Finally, focus must be given in the acoustics of specific, 'problematic' rooms, as for instance the orchestra pit.

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