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HEALTH & SAFETY LABORATORY

# Orchestra pilot of the industry / HSE noise guidance

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Science Group: **Human Factors**

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# EXECUTIVE SUMMARY

## Objectives

A professional orchestra piloted guidance for the music and entertainment sector on the Control of Noise at Work Regulations. The traditional arrangement of the orchestra was changed for a concert with pop musicians in an attempt to reduce the noise exposure of the orchestra musicians. Measurements were made to determine the effectiveness of the novel arrangement.

## Main Findings

Initial measurements were made during a rehearsal for a concert of light classical music. The orchestra was placed in a traditional arrangement with brass and percussion to the rear and strings to the front.

During the concert with the pop musicians, in addition to the sound of the orchestra, music was provided by backing tapes, backing and solo vocals, drums and electric guitars. The orchestra was placed behind the pop musicians, with the brass and percussion at the front, rather than the back of the orchestra. Low screens also separated the orchestra from the pop musicians. The sound level and balance was controlled electronically with separate microphones being used for each member of the orchestra.

The orchestra had reported that previous pop concerts had been very loud. The noise exposure of the woodwind and strings during the pop concert and rehearsals was generally reduced below the levels measured for the rehearsal of the light classical concert. The woodwind and string players at the back or edge of the orchestra received noise exposures below 85dB(A), while those further to the front remained at risk of receiving exposures close to or just above 85dB(A).

The orchestra's brass players receive daily exposures above 90dB(A). When other players are immediately in front of the brass section they can also receive exposures in excess of 90dB(A).

Short measurements of the peak levels in the percussion section reached a maximum of 132dB(C). Longer measurements may have given higher peak levels and hearing protection may be required to reduce peak exposure below the upper peak exposure value of the Control of Noise at Work Regulations. Peak levels are not a risk in other parts of the orchestra.

Measurements were made in the brass section of the noise level of musicians' headsets but these were inconclusive as the ambient noise dominated over the sound from the headset.

## Recommendations

Rearrangement of the orchestra to protect players from the sound of the loudest orchestra sections provides benefits for woodwind and string players.

Brass players should use hearing protection to comply with the Noise at Work Regulations 1989 as daily noise exposures can exceed 90dB(A).

# 1 INTRODUCTION

Until April 2008 the music and entertainment sector remains under the Noise at Work Regulations 1989 [1]. The Control of Noise at Work Regulations 2005 [2] then come into force for this sector. Representatives from the music and entertainment sector are preparing specific guidance with support from the Health and Safety Executive. Andrew Maxey, (HSE Noise and Vibration Programme) requested the Health and Safety Laboratory (HSL) make measurements supporting piloting of this guidance. This report details noise measurements of a professional orchestra that piloted the guidance.

Initial measurements were made at a rehearsal of a concert of light classical music using the full orchestra together with piano and vocal soloists. The orchestra was arranged in a standard arrangement with strings to the front and woodwind, brass and percussion to the rear. The rehearsal took place in the theatre to be used for the evening performance.

The event used to pilot the guidance was a concert of pop music with additional pop musicians. This event took place at the same theatre as the classical rehearsal mentioned above. The noise exposure of the members of the orchestra was measured at a large rehearsal studio on the Sunday, and on the Monday at the theatre during the afternoon rehearsal and evening performance. The orchestra was placed in a novel arrangement, planned by the orchestra production manager. The brass and percussion were in front while the strings and woodwind were on staging behind. At both the rehearsals and performance the pop musicians were in front of the orchestra with screens separating them from the orchestra. A plan of the arrangement used for rehearsal and performance at the theatre is given in Figure 1. The rehearsal studio was a larger space than the theatre stage; there a similar arrangement was used with some slight variations and increased spacing between musicians.

Each member of the orchestra was provided with a headset to hear the overall sound while microphones were placed in front of each individual instrument. The overall mix and level of the sound was controlled electronically. Additional music was provided from backing tracks, backing and solo vocals, electric guitars and drums.

# 2 MEASUREMENTS

## 2.1 CLASSICAL REHEARSAL

Selected members of the orchestra wore noise dosemeters to log both the A-weighted $L_{eq}$ and the C-weighted peak sound pressure at 15s intervals and record the overall sound levels. The dosemeter microphones were mounted on the shoulder. The players of the following instruments wore dosemeters:

- Trumpet
- Clarinet
- Violin
- Viola
- Cello

## 2.2 POP REHEARSALS AND CONCERT

As the musicians were using monitor headsets, the dosemeters could only record the ambient noise contributing to their exposure. The dosemeters were positioned at ear height within the orchestra and recorded the A-weighted Leq and the C-weighted peak sound pressure of the sound at 15s intervals as well as the overall sound levels.

The following positions were used:

Studio rehearsal

- Edge of brass section adjacent to the drummer's screens by the KEMAR head
- Clarinet at centre of back row of orchestra
- Violin in front row adjacent to brass section
- Viola in second row
- Cello at centre of front row of orchestra

Theatre rehearsal and performance

- Centre of brass section
- Immediately behind clarinet on back row of staging
- Violin in front row adjacent to brass section
- Viola in second row
- Behind cellist sitting immediately in front of oboe

Measurements were made during rehearsals at the rehearsal studio and the theatre to assess the noise exposure from a monitor headset of the same type as used by the orchestra musicians.

The headset was fitted to the KEMAR head, set to full volume and connected to a spare input socket in the brass section. The KEMAR head was positioned at the seated height of the musicians at the edge of the brass section adjacent to the drummer's screens. The sound at the ear of the KEMAR was recorded by a sound analyser, which provided third octave band analysis of the sound. Application of a frequency dependent transfer function converted the level at the ear to the equivalent diffuse field level in an open space.

Spot measurements were also made using a sound level meter / analyser at both venues.

A list of the instrumentation used is given in Appendix A of this report.

# 3 RESULTS

## 3.1 CLASSICAL REHEARSAL

Table 1 gives the overall A-weighted $L_{eq}$ (average sound level) and C-weighted peak level obtained from the musicians' dosemeters during the classical rehearsal. The $L_{EP,d}$ (daily noise exposure) reported is the contribution from the rehearsal and is missing the contribution from the evening performance. The actual $L_{EP,d}$ for the musicians is expected to be approximately 3dB higher.

Figure 2 plots the A-weighted $L_{eq}$ values recorded at 15s intervals for selected periods during the rehearsal. It should be noted that these are only approximately synchronised, with each dosemeter starting a 15s sample at a slightly different time.

## 3.2 POP REHEARSALS AND CONCERT

### 3.2.1 Ambient noise levels

Table 2 gives the overall $L_{eq}$ (average sound level) and C-weighted peak level obtained from the dosemeters during the rehearsals and performance, together with the $L_{EP,d}$ (daily noise exposure) arising from the ambient sound level. It should be noted that these ambient noise levels do not include the noise exposure from the musicians' headsets.

The dosemeters recorded the A-weighted $L_{eq}$ of the sound in 15s intervals. Selections of these results showing how the sound varied are shown in Figure 3. Figures 3a and 3b show selected periods at the rehearsal studio. Figures 3c and 3d show periods from the rehearsal at the theatre and Figure 3e shows a period from the performance. Figures 3c to 3e show sections where the same music was played. This gives an indication of how the levels varied between the rehearsals and performance.

### 3.2.2 Headset noise levels

Figures 4a and 4b plot the equivalent diffuse field A-weighted $L_{eq}$ in five-minute intervals, obtained from the KEMAR fitted with a musician's headset. This is compared to the ambient noise obtained from dosemeter measurements in the brass section for the same intervals.

Figure 4a shows the studio rehearsal results with the dosemeter by the KEMAR head. The overall $L_{eq}$ for both the headset sound measurement and the ambient noise is 89dB(A).

Figure 4b shows the theatre rehearsal results when the dosemeter was in the centre of the brass section while the KEMAR was to the side. The overall $L_{eq}$ for the headset measurement is 91.5dB(A) while the ambient noise in the centre of the brass section is 94.8dB(A).

### 3.2.3 Spot check measurements around orchestra

The results of spot measurements at the rehearsal studio and during the performance at the theatre are given in Table 3. Table 3 gives the A-weighted Leq, the difference in simultaneous measurements of the C-weighted and A-weighted $L_{eq}$, the C-weighted maximum peak level, and for the highest peak levels the difference in the C-weighted and A-weighted fast maximum level. It should be noted that the values in this table have been obtained from short duration measurements insufficient to determine daily noise exposure.

# 4 NOISE EXPOSURE AND EXPOSURE CONTROL

Under both the current Noise at Work Regulations and Control of Noise at Work Regulations there is a requirement to reduce noise exposure. Reduction of actual exposure is the first priority, with hearing protection being used only as a last resort.

## 4.1 BRASS SECTION

The highest sustained sound levels occur within the brass section. The overall measured $L_{eq}$ within the brass section for both the classical rehearsal and pop rehearsals and performance was between 93 to 95dB(A), and the daily noise exposure ($L_{EP,d}$) for the pop rehearsal and performance at the theatre was 93dB(A).

The rearrangement of the orchestra had little effect on the noise exposure of the brass players as their high noise levels arise from the brass instruments themselves. Increasing the spacing between players may give a limited reduction. Measurements show that sound levels at the side of the brass section are around 6dB lower than levels in the centre. This is an indication of the reduction that could be achieved if wider spacing is used.

## 4.2 PERCUSSION SECTION

Spot checks of the sound levels by the timpani player's ear confirmed high peak sound pressure levels occur in the percussion section. Peak levels reached 132dB(C) during a 2-minute measurement during the pop rehearsal. The Control of Noise at Work Regulations lower peak action value is 135dB(C) and there is a risk that this may be exceeded.

Reduction of the peak noise levels will only be achieved by quietening the percussion instruments themselves.

## 4.3 EXPOSURE REDUCTION BY REARRANGEMENT OF ORCHESTRA

The traditional arrangement of the orchestra places the loudest instruments at the back and the quieter instruments to the front. This arrangement increases the noise exposure of quieter musicians in front of the louder sections. The increased exposure is due to both the direct sound and the need for the musicians to play louder in order to hear their own playing. In the classical rehearsal the woodwind was in front of the brass section. The clarinettist recorded an $L_{eq}$ of 92dB(A), just 1dB lower than the trumpet player. During musical sections when the brass was not playing the sound level recorded for the clarinettist dropped by 5 to 10dB.

For the pop rehearsal and performance the brass and percussion sections were placed at the front of the orchestra, and the pop musicians were forward of these with screens separating them from the orchestra. The balance of sound was controlled electronically. The orchestra had said in their experience such concerts were usually far louder than a classical concert, with sound levels at the performance being higher than at the rehearsal. There was no perceptible increase in the sound levels between the rehearsals and performance of the pop concert, and generally the ambient sound level around the quieter instruments in the orchestra was lower than at the classical concert rehearsal. The brass and percussion players may have received a small increase in noise exposure from the rest of the orchestra in this forward position. However this increase was not perceptible in the results reported as the sound from their own instruments dominated.

The players receiving the lowest noise exposures were those playing quieter instruments when positioned at the back or side of the orchestra. Exposure increases when players are sitting in

front of other players. For the classical rehearsal and for the pop rehearsal at the rehearsal studio the cellists were at the side of the orchestra and their $L_{eq}$ was 84dB(A) and 83dB(A) respectively. For the pop rehearsal and concert at the theatre the cellists were in front of the woodwind and the $L_{eq}$ increased to between 86 and 87dB(A). For the pop rehearsals and performance the clarinettists were on the back row of the orchestra and their $L_{eq}$ was between 80 and 82dB(A); at least 10dB lower than during the classical rehearsal when they were in front of the brass section.

The success of the rearrangement of the orchestra was also due to the awareness of the conductor, musicians and technicians of the need to keep the sound levels on the stage as low as possible. This need was accepted reluctantly by some of the pop musicians. It is important that when outside technicians and musicians play with an orchestra that they are made aware of how the noise exposure of the orchestra is controlled.

## 4.4 NOISE EXPOSURE FROM HEADSETS

The rearrangement of the orchestra for the pop concert was possible because the overall sound balance was controlled electronically. The players heard the sound through bi-aural headsets. Many of the players chose to wear the headset over one ear only so that they could still hear the sound of their own playing. The noise exposure of the musicians is therefore made up of both the ambient noise around them and the sound from the headset.

Measurements of the headset noise exposure were made with a headset fitted to the KEMAR head while positioned to the side of the brass section. The above overall $L_{eq}$ results and the plot of the headset and ambient sound levels (Figures 4a, and 4b) confirm the KEMAR measurement in the brass section is dominated by the ambient sound, and the sound from the headset has not significantly added to the noise exposure of the brass musicians, and the headset provides no significant sound attenuation. How much the headset sound contributes to the noise exposure of musicians in quieter sections of the orchestra is indeterminate from these results.

Mon-aural (single ear) headsets may be preferable for use by musicians where they want to keep one ear uncovered. Another alternative is to use headsets that provide sound attenuation. This enables musicians to listen at lower levels and to be protected against the ambient sound.

# 5 HEARING PROTECTION

Under the Noise at Work Regulations hearing protection must be worn when daily exposures exceed 90dB(A), or if there is a risk of exposure to peak levels above 140dB. Under the Control of Noise at Work Regulations hearing protection must be worn when the daily exposure exceeds 85dB(A), or there is a risk of exposure to peak levels in excess of 137dB(A).

The attenuation of any protector is frequency dependent. High frequencies are more easily attenuated than low frequencies. The difference in the C and A-weighted levels is an indication of the frequency content of sound. High C minus A values indicate a low frequency content, low or negative C minus A values indicate a high frequency content. The C minus A value is used to estimate the attenuation of hearing protection together with the H, M and L values of the protector. Further details on using this data is given in Controlling Noise at Work [3] and in EN 458 [4].

C minus A values measured simultaneously during spot measurements are shown in Table 3. The C minus A values over 10dB shown for some measurements suggest hearing protection will provide only low levels of protection, however it should be noted that these values correspond to low A-weighted sound levels. In these results the C minus A values tend to decrease as the A-weighted level of the sound increases.

Under the Control of Noise at Work Regulations the estimated attenuation of hearing protection should be sufficient to reduce exposure below the upper exposure action values which are 85dB(A) daily exposure, and 137dB(C) peak exposure.

If musicians use headsets there may be some advantage in using headsets that provide some sound attenuation.

## 5.1 BRASS SECTION

The brass players should use hearing protection in order to comply with both the new and the current Regulations. When playing for a full day daily exposure is likely to exceed 90dB(A).

A C minus A value of 4dB was measured for the back of the brass section when the A-weighted $L_{eq}$ was 100dB.

## 5.2 PERCUSSION SECTION

Short measurements by the timpani player show peak levels reaching 132dB(C). Longer measurements may have shown higher peak sound pressure levels. Hearing protection will need to be worn by percussion players to prevent peak exposures above 137dB(C) under the Control of Noise at Work Regulations.

The method for selecting hearing protection against high peak sound pressures also uses the H, M and L values of the protector. The frequency content of the sound is determined by comparison with example sounds given, however musical instruments are not included in these. The Fast maximum C minus A values also give an indication of the frequency content of the sound contributing to the peak level. The values are between 7 and 8dB (Table 3), indicating a low to mid frequency sound. The estimated attenuation of the peak level provided by a hearing protector (according to the standard method in EN 458) will correspond to the L value of the protector minus 5dB.

## 5.3 OTHER ORCHESTRA SECTIONS

When players of quieter instruments are positioned at the side or back of the orchestra it will be possible to reduce their daily noise exposure below 85dB(A). The use of hearing protection would then be voluntary under the Control of Noise at Work Regulations rather than mandatory.

Players at the front or within the body the orchestra will be at risk of exceeding a daily exposure of 85dB(A) and low attenuation hearing protection may still be required when the Control of Noise at Work Regulations come into force.

# 6 RECOMMENDATIONS

## 6.1 NOISE CONTROL

Placing the brass and percussion players to the front of the orchestra reduces the noise exposure of the woodwind and string players.

Rearrangement of the orchestra relied on electronic control of the sound balance. It is essential that technicians controlling the sound are aware of the need to control the noise exposure of musicians. A practical way of achieving this control may be to have an indication of the actual sound pressure level somewhere in the orchestra.

Other noise control measures also need to be considered in conjunction with the rearrangement of the orchestra. These may include balancing of loud and quiet pieces in a programme.

## 6.2 HEARING PROTECTION

Hearing protection is used when a risk exists after noise control measures have been made or as a temporary measure until noise control measures remove the risk.

The brass players are receiving daily noise exposures in excess of 90dB(A) and so are required to use hearing protection under the existing Noise at Work Regulations, and this requirement will continue under the Control of Noise at Work Regulations.

During a full day's playing all members of the orchestra are likely to receive daily exposures in excess of the 80dB(A) lower action value and that all but woodwind and string players at the back or side edges of the orchestra will be at risk of exceeding 85dB(A), the upper action value of the Control of Noise at Work Regulations.

Peak levels measured by the timpani player suggest there is a risk that the peak action values may also be exceeded in the percussion section.

When the Control of Noise at Work Regulations come into force hearing protection must be provided when exposure exceeds the lower action values and used when there is a risk that the upper action values may be exceeded. Players will need time to adjust to wearing protectors before the Regulations come into force.

Selected hearing protectors should reduce daily exposure to below the upper exposure action value while avoiding over protection, and excessive hearing impairment. CE marked flat frequency response protectors that provide a minimal level of protection are likely to be most suitable. A range of protectors should be provided initially so that orchestra members have a choice.

# 7 TABLES

**Table 1 Overall musicians' noise exposure during the classical rehearsal**

| ***Musician's instrument*** | ***$L_{eq}$ dB(A)*** | ***Maximum peak sound level dB(C)*** | ***$L_{EP,d}$ dB(A)**** |
|---|---|---|---|
| Trumpet | 93 | 123 | *89* |
| Clarinet | 92 | 121 | *88* |
| Violin | 89 | 116 | *85* |
| Viola | 88 | 119 | *84* |
| Cello | 84 | 120 | *80* |

**Table 2 Ambient noise levels in orchestra during the pop rehearsals and performance**

| ***Measurement position*** | ***$L_{eq}$ dB(A)*** | ***Maximum peak sound level dB(C)*** | ***$L_{EP,d}$ dB(A)**** |
|---|---|---|---|
| ***Sunday studio rehearsal*** | | | |
| Side of brass section | 88 | 124 | **87** |
| Clarinet | 82 | 117 | **81** |
| Violin | 86 | 120 | **85** |
| Viola | 83 | Not available | **82** |
| Cello | 83 | 122 | **82** |
| ***Monday afternoon theatre rehearsal*** | | | |
| Centre of brass section | 95 | 131 | *91* |
| Clarinet | 81 | 115 | *77* |
| Violin | 88 | 120 | *84* |
| Viola | 86 | 121 | *82* |
| Cello | 87 | 119 | *83* |
| ***Monday evening performance*** | | | |
| Centre of brass section | 93 | 132 | **93**, *90* |
| Clarinet | 80 | 115 | **80**, *77* |
| Violin | Not measured | | |
| Viola | 85 | 122 | **84**, *81* |
| Cello | 86 | 120 | **86**, *83* |

**Value measured for part of day shown in italics, overall daily exposure from ambient noise shown as bold.*

**Table 3 Results of spot noise measurements around orchestra during pop rehearsals and concert**

| *Measurement* | *$L_{eq}$ dB(A)* | *C minus A $L_{eq}$ dB* | *Maximum peak level dB(C)* | *C minus A Fast max dB* |
|---|---|---|---|---|
| ***Rehearsal studio*** | | | | |
| French horn at back of brass section | 100 | 4 | 118 | |
| Violins | 85 | 4 | 108 | |
| Rear row of violins | 90 | 2 | 112 | |
| Harp | 92 | 6 | 114 | |
| Cello | 87 | 2 | 106 | |
| Between clarinet and bassoon | 85 | 4 | 112 | |
| Timpani – measurement 1 | 89 | 8 | 112 | |
| Timpani (3s drum roll) – measurement 2 | 97 | 9 | 122 | |
| Timpani – measurement 3 | 93 | 6 | 131 | 7 |
| Timpani – measurement 4 | 92 | 7 | 132 | 8 |
| Side of control console | 83 | 10 | 113 | |
| At control console | 89 | 4 | 111 | |
| ***Theatre performance (measurements at edge of stage)*** | | | | |
| Side of stage by violins | 83 | 5 | 111 | |
| Back of stage by double bass | 85 | 8 | 114 | |
| Woodwind side - measurement 1 during film | 79 | 13 | 111 | |
| Woodwind side – measurement 2 | 81 | 9 | 111 | |
| Woodwind side – measurement 3 | 83 | 12 | 111 | |
| Side of strings Robbie Williams solo | 88 | 6 | 114 | |
| Behind brass | 87 | 10 | 114 | |
| Back of stage | 86 | 12 | 114 | |
| ***Theatre performance (measurements at fixed position on raised area at side of stage)*** | | | | |
| At 19.45 | 87 | 4 | 108 | |
| At 20.15 | 84 | 8 | 112 | |
| At 21.01 | 81 | 8 | 106 | |
| At 21.26 | 82 | 12 | 113 | |

# 8 FIGURES

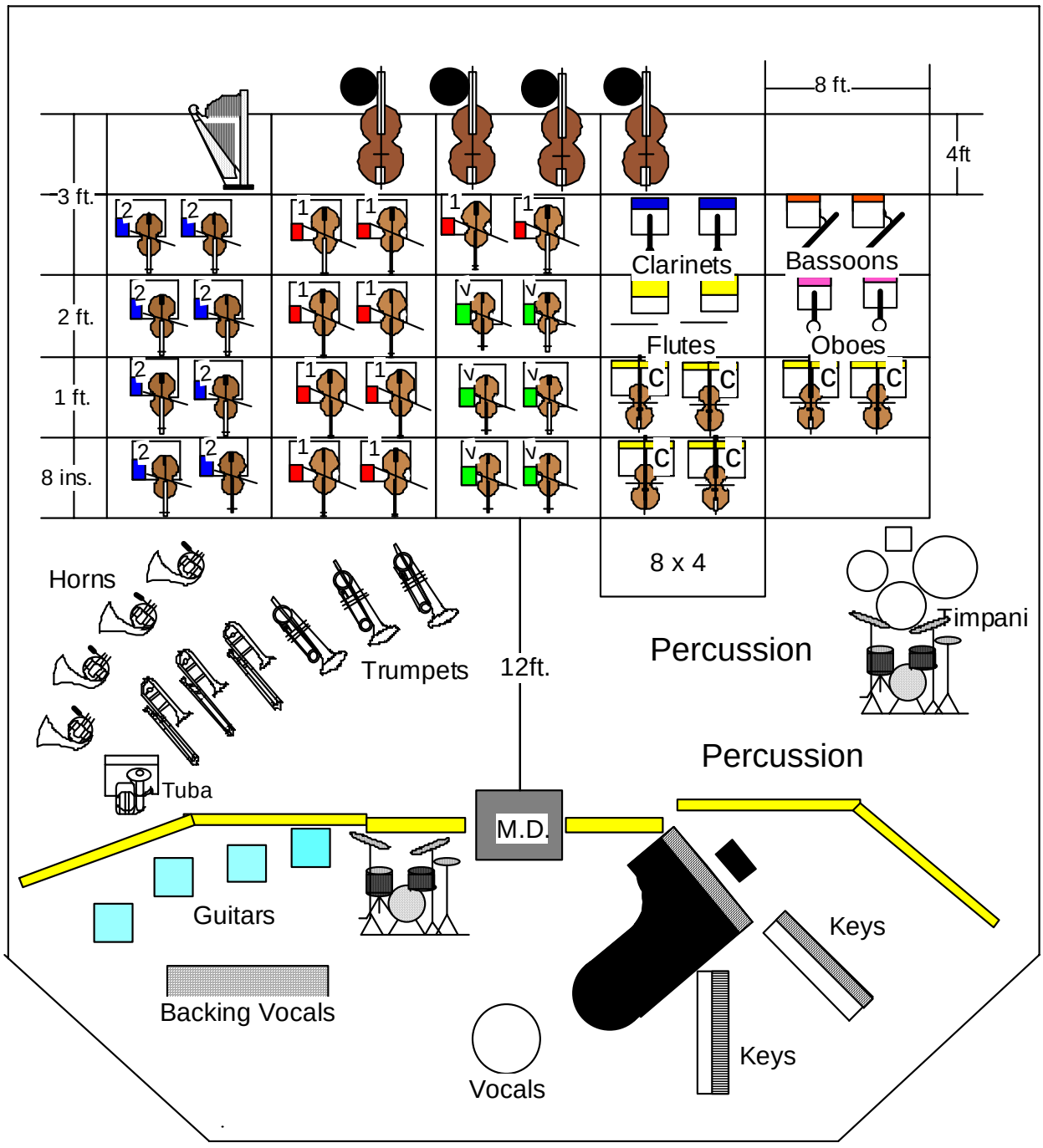
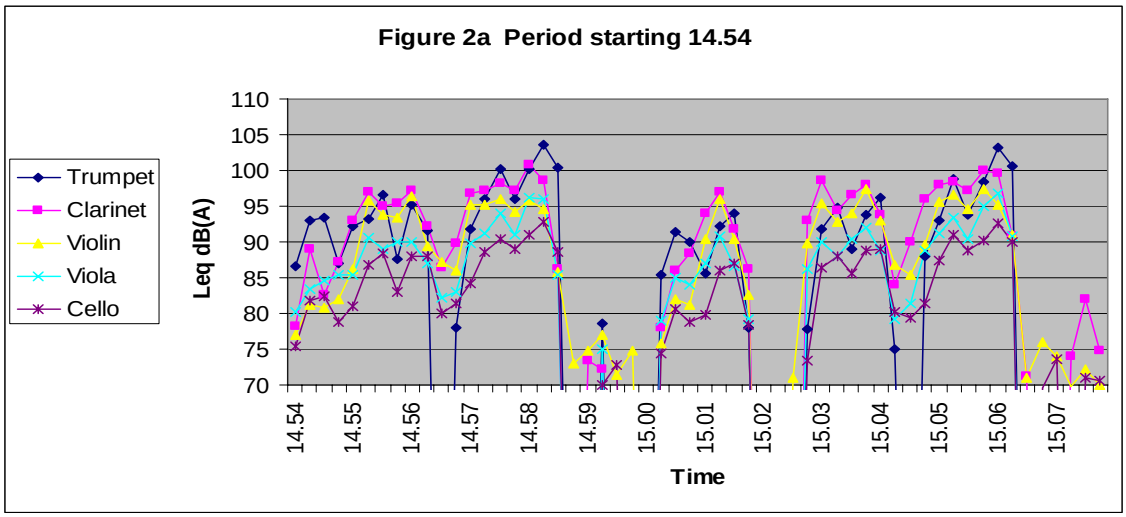
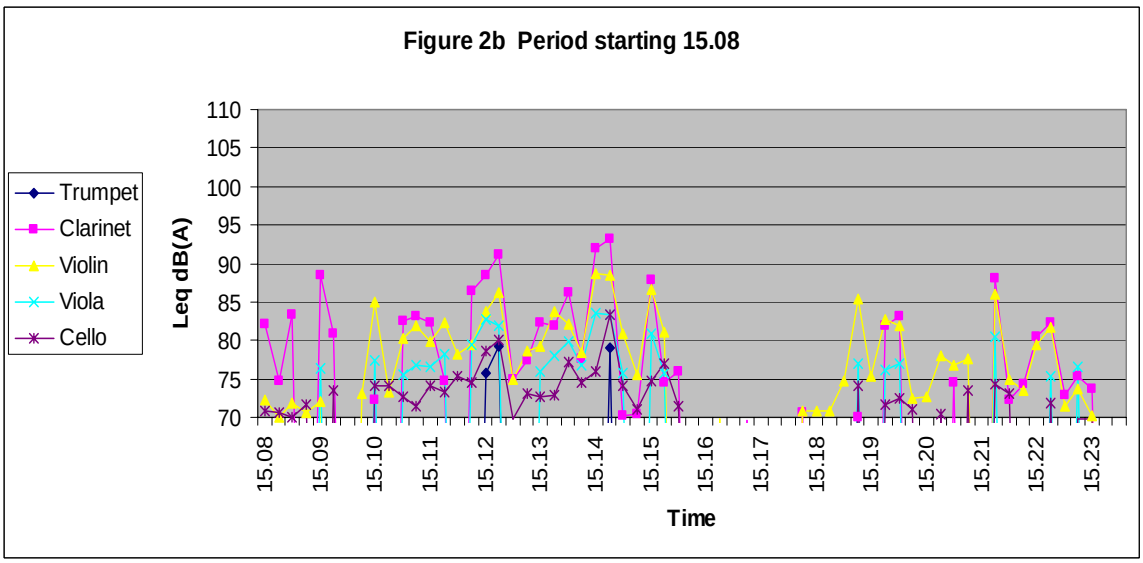
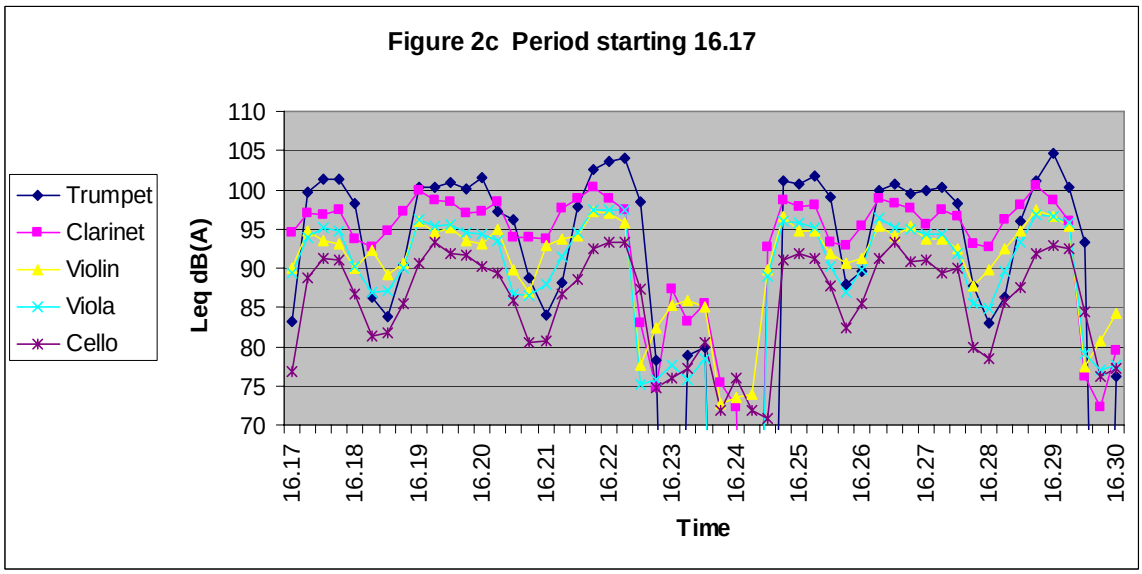



**Figure 1 Pop concert layout at theatre**

**Figure 2 Sample dosemeter records – Classical concert rehearsal**



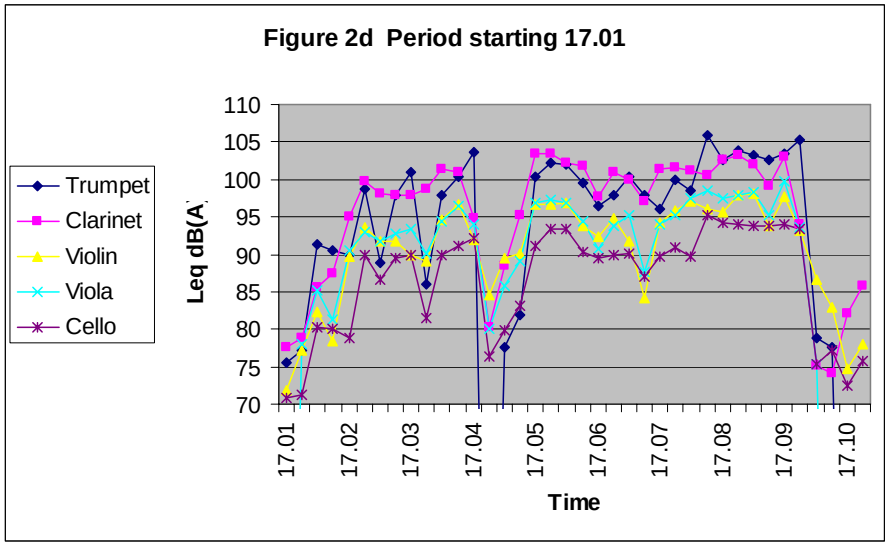
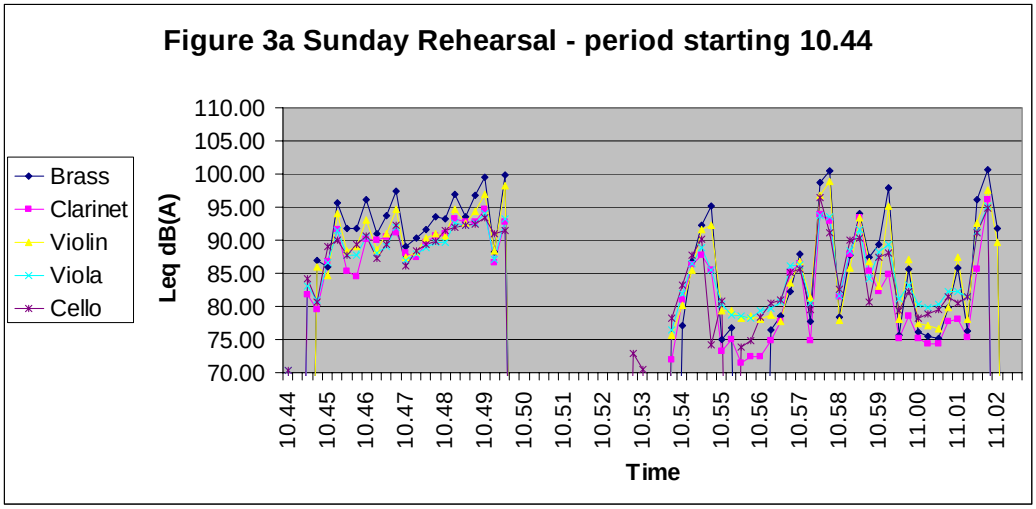
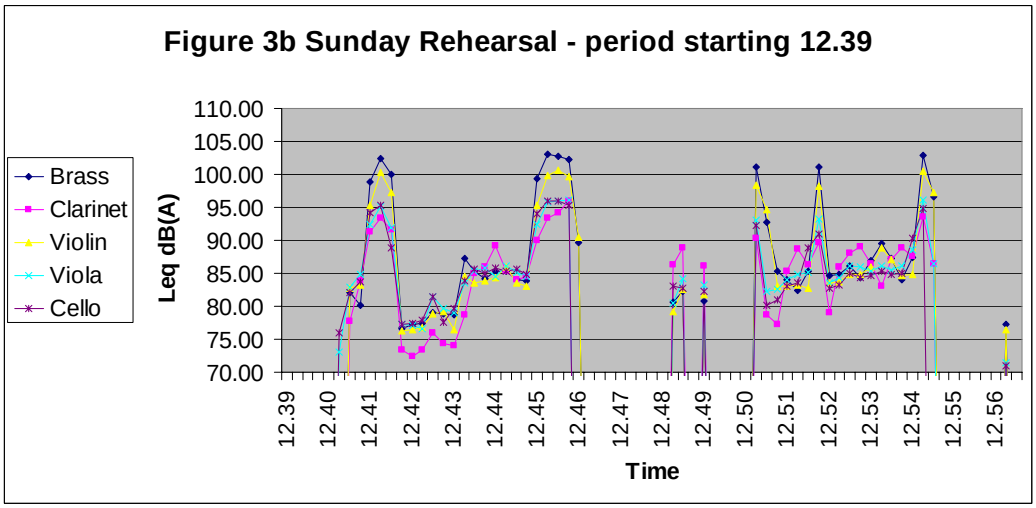
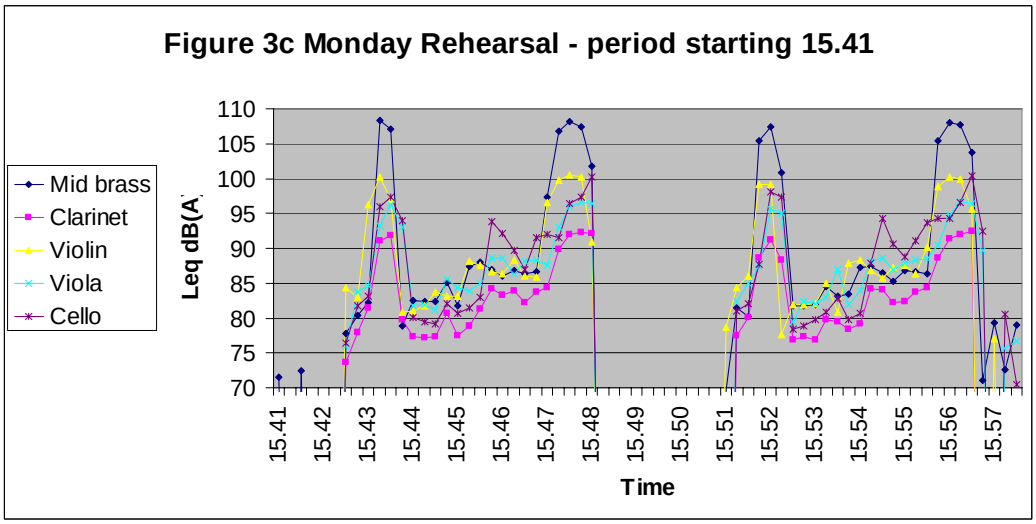


Figure 2d Period starting 17.01
Trumpet
Clarinet
Violin
Viola
Cello
Leq dB(A
110
105
100
95
90
85
80
75
70
17.01
17.02
17.03
17.04
17.05
17.06
17.07
17.08
17.09
17.10
Time

**Figure 3 Sample dosemeter records – Pop concert**



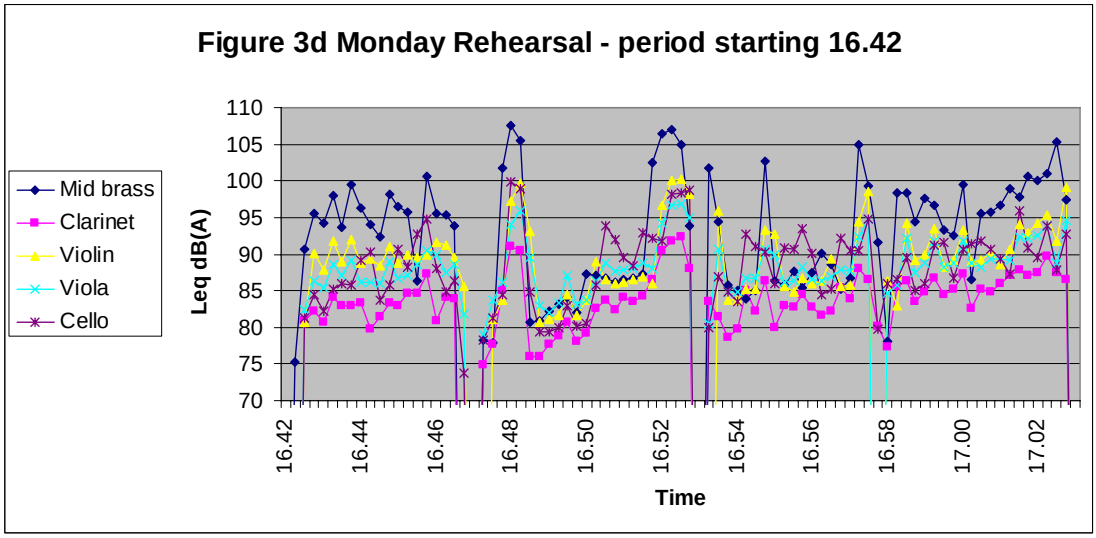


Figure 3d Monday Rehearsal - period starting 16.42
Mid brass
Clarinet
Violin
Viola
Cello
Leq dB(A)
110
105
100
95
90
85
80
75
70
16.42
16.44
16.46
16.48
16.50
16.52
16.54
16.56
16.58
17.00
17.02
Time

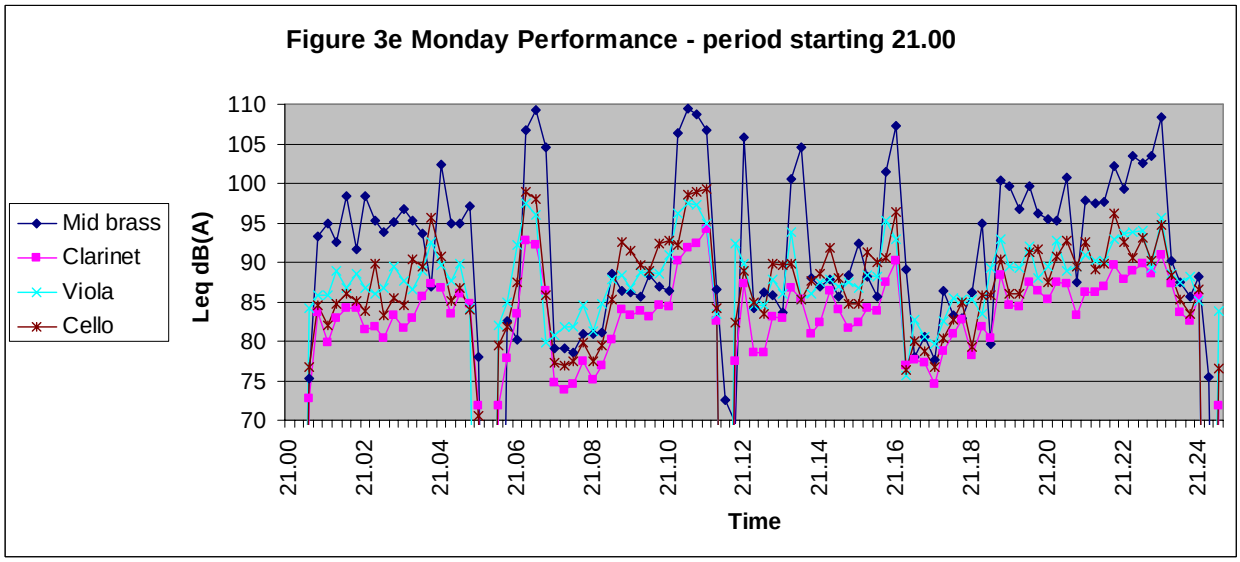
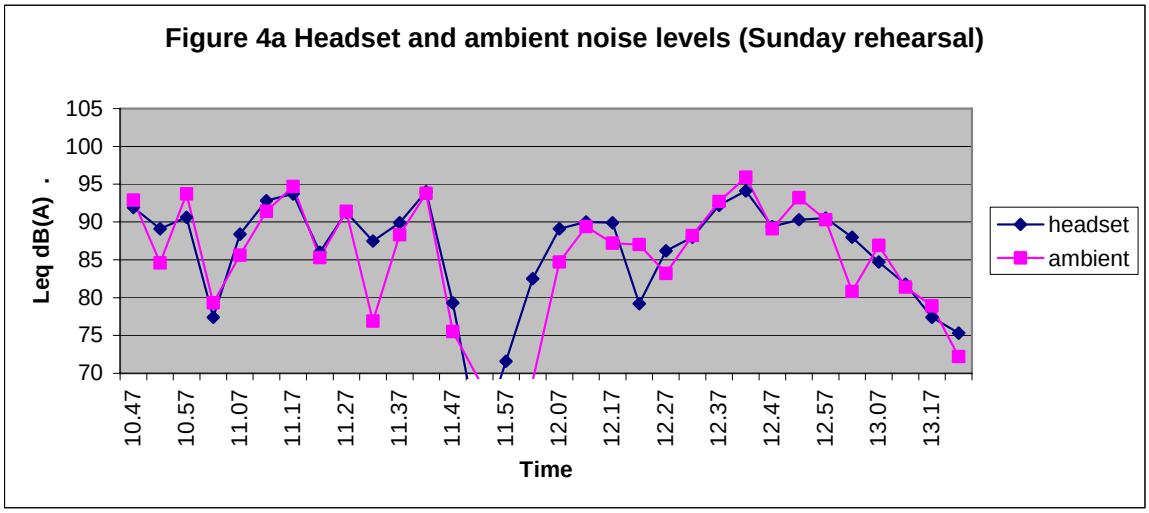
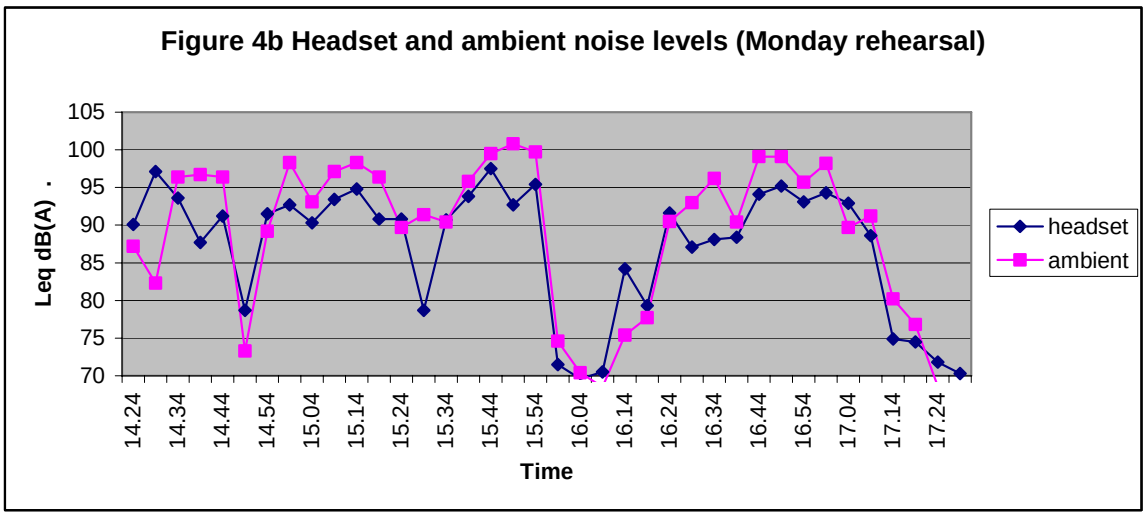


Figure 3e Monday Performance - period starting 21.00
Mid brass
Clarinet
Viola
Cello
Leq dB(A)
110
105
100
95
90
85
80
75
70
21.00
21.02
21.04
21.06
21.08
21.10
21.12
21.14
21.16
21.18
21.20
21.22
21.24
Time

**Figure 4 Noise levels recorded in brass section, from KEMAR fitted with musician's headset and ambient noise from dosemeter measurement.**

Figure 4a KEMAR at side of brass section, dosemeter adjacent to KEMAR
Figure 4b KEMAR at side of brass section, dosemeter in centre of brass section



# 9 REFERENCES


1. **Noise at Work Regulations 1989** Statutory Instrument 1989 No 1790 – Health and Safety Regulations 1989

2. **Control of Noise at Work Regulations 2005** Statutory Instrument 2005 No. 1643 Health and Safety

3. **Controlling noise at work** – The control of noise at work regulations 2005 – Health and Safety Executive guidance on regulations. HSE Books.

4. **BS EN 458:2004 Hearing protectors**. Recommendations for selection, use, care and maintenance. Guidance document.

# 10 APPENDIX A

## Measurement and analysis equipment

- B&K 2260 sound level meter/ analyser serial number 2305154 with B&K 4189 microphone serial number 2294166 and B&K 4231sound calibrator serial number 2309005

  UKAS calibration May 2005
  Meter conformance to IEC 60804, and IEC 60651 Type 1 and calibrator to IEC 942:1988 Class 1

- CEL 360 logging noise dosemeters serial numbers 3/026936, 3/026937, and 3/026938 with CEL 110 acoustic calibrator serial number 026392

  Manufacturer's calibration March 2006
  Meter conformance to IEC 60804 Type 2, IEC 60651 Type 2, and IEC 1252. CEL sound calibrator conformance to IEC 60942 Class 2C

- CEL 460 logging noise dosemeters serial numbers 0691603, and 0691607 used with CEL 110 acoustic calibrator serial number 026392 (as above).

  Calibration by Health and Safety Laboratory Noise and Vibration Section March 2006
  Meter conformance to IEC 60804 Type 2, IEC 60651 Type 2, and IEC 1252.

- Knowles Electronics Manikin for Acoustic Research (KEMAR) fitted with B&K 4134 microphone serial number 799939 and B&K 2619 microphone preamplifier serial number 609001.

  Calibrated by Health and Safety Laboratory Noise and Vibration Section
  Microphone January 2005, preamplifier October 2005.