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NOISE SURVEYS OF ORCHESTRAL MUSICIANS AT THE BARBICAN CONCERT HALL

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1. INTRODUCTION

The acoustic design of auditoria has traditionally been concerned primarily with providing ideal listening conditions for concert audiences, and also good playing conditions for performers. However, the needs of the performers with respect to their working conditions, in particular their aural environment, are often overlooked.

In the past thirty years the issue of possible hearing loss among orchestral musicians, and the levels of sound to which they are exposed within orchestras, have been the subject of several investigations [1-17]. Orchestral managements and players themselves are becoming increasingly concerned about potential damage to hearing and in some cases have introduced measures to reduce risk [1-5]. These include the wearing of hearing protective devices such as ear plugs or muffs, the use of shields or baffles to attenuate the sound between players, or rearrangement of the layout of the orchestra. However, some of these measures have been found to be ineffective, or unpopular with the musicians themselves.

This paper reports the results of a recent study [18] carried out to investigate the noise exposure of orchestral musicians, and to quantify the risk of hearing damage among members of an orchestra. Noise monitoring of musicians took place over several months during rehearsals of a wide variety of orchestral works. A subjective questionnaire survey of the performers was also undertaken to determine their awareness of, and response to, possible hearing hazards, and to establish typical working patterns of musicians. The measured noise levels together with the results of the questionnaire survey were used to estimate personal noise exposures of orchestral musicians over a typical working week.

2. SUBJECTIVE ASSESSMENT OF NOISE EXPOSURE

2.1 Questionnaire design

The subjective views of the orchestra members with regard to their noise exposure were obtained by use of a questionnaire. The questionnaire was designed to obtain a general overview of the opinion of the orchestra members with regard to noise exposure and potential damage to hearing.

Some of the questions were designed to obtain factual information relating to an individual's position in the orchestra and duration of noise exposure in terms of concert, rehearsal and personal practice time.

Other questions sought more subjective responses regarding noise exposure. For example, the players were asked whether they considered themselves to be exposed to high sound levels, and which instruments they considered to be the sources of high sound levels. In addition they were

asked their opinion of potential hearing damage and preferred sound control measures. There was space at the end of the questionnaire for any additional comments.

Approximately 100 copies of the questionnaire were sent directly to the London Symphony Orchestra at the Barbican Hall, London, for internal distribution amongst the orchestra members. 38 completed questionnaires were returned from 27 string players, 6 woodwind players, and 5 brass players.

2.2 Sources of high noise levels

Of the 38 orchestra members who responded to the survey, 33 (87%) considered themselves exposed to high sound levels within the orchestra. Of those, only four (3 violinists and 1 French horn player) felt that they were exposed to high sound levels from their own instrument, although 11 players regarded their own instrument as a source of high sound levels.

33 players cited the brass section, in particular the trumpet and/or trombone, as being a cause of high sound levels; 24 players cited the percussion section (in particular the timpani); and 15 players cited the woodwind section (of whom 10 specified the piccolo).

Violinists and the harpist felt that they were exposed to high noise levels from timpani and piccolo. (many violinists were seated near to or in front of the piccolo). The viola players, cellists and double bass players perceived the brass section as causing the highest noise levels, with the cellists also citing the percussion section as contributing to their high noise exposure. Both woodwind and brass sections attributed high noise exposure to the brass and percussion.

2.3 Hazard to hearing

The majority of respondents, 27 players (71%), considered the high sound levels in the orchestra to be a hazard to hearing; of these, 24 (63%) were concerned about their own hearing. Two violinists admitted to having poorer hearing in the left ear, which is the ear closest to the instrument. This is consistent with the findings of other studies [9-13], which have shown some violinists and viola players to have greater hearing loss in the left ear than the right. The harp player was also concerned about her hearing, which in her opinion is less good in the ear up against the harp.

2.4 Preferred noise control measures

Players were asked what, if any, measures they would like to see used to reduce sound levels or to protect their hearing. The use of plastic screens was by far the most popular choice as a potential mitigation measure, with 15 players suggesting that screens should be used. Other common suggestions included the repositioning of instruments within the orchestra, increasing the distance between players, and the use of risers for some instrument sections.

A few musicians currently make their own attempts at noise mitigation by, for example, putting their fingers in their ears during rehearsals, leaning forward as much as possible during concerts and using earplugs. The latter is not a popular option, with several musicians stating that the use of earplugs was "extremely unsatisfactory" as it hindered good ensemble playing.

2.5 Comments on halls

A number of musicians volunteered information about the Barbican Hall, drawing comparisons with other halls, although this information was not specifically requested in the questionnaire. A common complaint about the Barbican Hall was that the musicians are too cramped with a lack of space between them. The "boxed in" walls around the stage were also mentioned as a causative factor in the high sound levels experienced.

Several other concert halls were mentioned as being 'better' than the Barbican Hall with regard to the noise levels produced on the stage. These included the Berlin Philharmonie, the Royal Festival Hall, London, and St David's Hall, Cardiff as examples of 'open' halls with more space behind the stage so that there is not such a great intensity of reflected sound incident on the musicians. Huddersfield Town Hall and Leeds Town Hall were also mentioned as example of halls which have steeper raking on the stage so that nobody plays 'into the back' of anyone else.

2.6 Duration of Activities

The musicians were asked to estimate how much time they spend each week in a full orchestral rehearsal, playing in concerts, and in other musical activities such as private or group practice, session work, and teaching. The figures given were remarkably consistent, and the average times for each orchestral section are shown in Table 1 in terms of mean hours per week.

Table 1. Time spent per week in musical activities

Instrument section	Hours per week (mean value)		
	Rehearsal	Concert	Other
Strings	23	6	11
Woodwind	22	9	11
Brass	22	7	8
Overall	22	7	11

As shown above, as a whole the orchestra spends approximately 22 hours in rehearsal and 7 hours in concert per week, a total of around 29 hours. The time spent in other musical activities is typically around 11 hours per week. The total number of hours per week spent in musical activities is thus approximately 40 hours.

3. THE NOISE SURVEY

Noise monitoring was undertaken during eleven rehearsals of the London Symphony Orchestra on the stage of the Barbican Hall, London, between May and November 1997. Personal noise exposure levels of individual musicians were obtained using dosemeter type equipment. General noise levels in front of the conductor were also obtained at some rehearsals where space permitted, using a sound level meter.

3.1 Music played

All rehearsals consisted of more than one session, separated by a break. Ten rehearsals consisted of two sessions, and one of four sessions, giving a total of twenty-four measurement sessions, varying in length from 50 minutes to 2 hours 50 minutes. Altogether, the playing of twelve pieces of music, including symphonies by Brahms, Vaughan-Williams, Shostakovich, Rachmaninov and Mahler, was monitored. The details of the rehearsals monitored, including the pieces played and the performers involved at each rehearsal, are shown in Table 2. It can be seen that more than one piece of music was played at some rehearsals, and that some pieces were rehearsed over several sessions, sometimes with different combinations of performers.

Table 2. Details of rehearsals

Rehearsal Number	No. of Sessions	Composer	Pieces played	Performers	Type
1	2	Hallowell	'Do not disturb' suite	Orchestra & children's choir	Medium
		Brahms	Symphony no.1	Orchestra	Light
		Beethoven	Violin Concerto	Orchestra & soloist	Light
2	2	Ravel	Rhapsodie Espagnol Le Tombeau de Couperin L'heure Espagnol	Orchestra	Light
3	2	Ravel	L'heure Espagnol	Orchestra & vocalists	Light
4	2	Bernstein	A White House Cantata	Orchestra	Light
5	2	Bernstein	A White House Cantata	Orchestra & chorus/vocalists	Medium
6	2	Vaughan-Williams	London Symphony 'The Wasps' Overture	Orchestra	Medium
7	4	Shostakovich	Symphony no. 7 ('Leningrad')	Orchestra	Heavy
8	2	Shostakovich	Symphony no. 7 ('Leningrad')	Orchestra	Heavy
9	2	Rachmaninov	Symphony no. 3	Orchestra	Medium
10	2	Mahler	Symphony no. 7	Orchestra	Heavy
11	2	Mahler	Symphony no. 7	Orchestra	Heavy

For the purpose of subsequent analysis, the music played was classified according to three types: 'light', medium' and 'heavy'. This classification is similar to that used by Jansson and Karlsson [9]. The classification involved a subjective judgement, based upon the observed content of each piece with regard to intensity and orchestration. Pieces that are generally quiet, with little brass or percussion content and scored mostly for strings and woodwind, have been classified as 'light'. The 'medium' classification contains pieces of moderate intensity, with increased brass, woodwind and percussion content. Loud pieces with a high brass and percussion content are classified as 'heavy'. The classification of each piece is also shown in Table 2. It should be noted that a piece may have different classifications at different rehearsals, depending upon the performers involved in each rehearsal.

3.2 Noise measurements

During the rehearsals the L_{Aeq} levels to which the players were exposed were obtained by attaching dosemeter type equipment to the musicians. For violinists and violists, the dosemeter microphone was generally attached in such a way as to not obstruct instrument use, either on the right hand shoulder or collar, or on the back situated above the shoulder blade on the left hand side. For other musicians the microphone was attached to the shoulder or collar, positioned so as not to interfere with the playing of the instrument. The measurements obtained were analysed to obtain the players' noise exposures in terms of L_{Aeq} levels over each rehearsal session. The number of sessions measured for each type of instrument ranged from 1 for each of the flute and piccolo to 16 for the violins. For all instruments, apart from the flute and piccolo, measurements were made at several positions in the orchestra. Two or three positions were measured for the other woodwind instruments and the violas; four for the trumpet, trombones and cellos; and six positions for the violins and basses. This enabled the effect of position relative to other instruments to be studied. There was also an opportunity for a single measurement of the effectiveness of a screen.

During rehearsals of the Shostakovich, Rachmaninov and Mahler symphonies the peak noise levels in unweighted dB occurring during each session were recorded for several players.

3.3 Measured levels

The noise levels presented are those resulting only from the actual rehearsal time; noise from the breaks and any other non-rehearsal activity has been excluded from the analysis. The L_{Aeq} levels measured are referred to as the 'rehearsal activity levels'.

Table 3 shows the range and mean values of the rehearsal activity levels measured in each session for individual instruments, for each music type. The rehearsal activity levels measured for the strings range from 81 to 94 dB(A); for the woodwind from 81 to 97 dB(A); and for the brass from 84 to 103 dB(A).

The peak levels monitored at five rehearsals are shown in Table 4. It can be seen that a trombone player was exposed to a peak level of greater than 140 dB, during the rehearsal of the Shostakovich Leningrad Symphony. The French horn and trumpet players were exposed to levels of above 130 dB during the rehearsal of this piece, and during the rehearsal of the Rachmaninov and Mahler symphonies.

Tables 3 and 4 show that the brass players experience the highest noise exposure, in terms of both rehearsal activity levels and peak levels.

3.4 Effect of screen

During one rehearsal session measurements were made of a bassoonist and contra-bassoonist sitting next to each other in front of the French horns. The contra-bassoonist had a clear plastic shield behind his head intended to attenuate the noise from the French horns. However, the L_{Aeq} levels measured for each player for the session were identical at 84 dB(A), suggesting either that the main cause of noise exposure was the player's own instrument, or that the screen was totally ineffective in protecting against the noise from the horns.

Table 3. Range and mean (in italic) of rehearsal activity levels (dB L_{Aeq}) for different categories of music

Orchestral position	Music type		
	Light	Medium	Heavy
Violin	81-86 *84*	91-92 *91*	91-92 *91*
Viola	87-89 *88*	90-93 *92*	91-91 *92*
Cello	81-83 *82*	88 *88*	92 *92*
Double bass	84-89 *87*	86-93 *90*	90-91 *90*
Bassoon/ Contra-Bassoon	84-91 *88*	88-93 *91*	92-93 *93*
Clarinet	-	-	96-99 *98*
Flute/Piccolo	88-93 *91*	-	-
Oboe/Cor anglais	81-84 *83*	89-92 *91*	88-94 *92*
French horn	-	90 *90*	96 *96*
Trombone	86-88 *87*	88-94 *92*	93-98 *96*
Trumpet	84-91 *89*	91-99 *97*	95-103 *100*

Table 4. Peak levels (dB) measured at 5 rehearsals

Rehearsal	Music	Instrument	Peak level (dB)
7	Shostakovich Symphony no. 7 'Leningrad'	Violin	108
7		Bassoon	127
7		French Horn	130
7		Trombone	142
8		Clarinet	128
8		Trombone	130
8		Trumpet	134
8		French Horn	132
9	Rachmaninov Symphony no. 3	Bassoon	125
9		French Horn	133
9		Trombone	123
9		Trumpet	129
10	Mahler Symphony no.7	Trumpet	129
10		Double Bass	120
10		Cor Anglais	120
10		Contra-bassoon	124
11		Violin	120
11		Violin	124
11		Trumpet	130
11		Trombone	127

3.5 Variation of noise levels with position and music played

The noise exposure received by an individual player is dependent upon the particular instrument played, the piece of music played, and the player's position relative to other instruments in the orchestra. Table 3 shows that there can be a difference of up to 20 dB(A) over all the rehearsal activity levels measured for each instrument over the twenty-four sessions, with differences of up to 8 dB(A) for each instrument within the three music types. To examine further the variation in noise exposure of each player, the position of each player in relation to other instruments at the time of measurement was recorded. For example, measurements of violins were made at six different positions relative to other instruments, as shown in Table 5.

It appears from the levels shown in Table 5 that type of music, rather than position in the orchestra or proximity to other instruments, is the dominant factor determining noise exposure. In particular, it can be seen that for the violins there is no difference in the levels measured in front of the brass section and in front of the woodwind. This same pattern was observed for the other instruments measured at different positions.

Table 5. Rehearsal activity levels (dB L_{Aeq}) for violinists in different positions

Instrument	Position	Music type		
		Light	Medium	Heavy
Violin	In front of flute	81	91	92
	In front of piccolo	86		
	In front of oboe		92	91
	In front of oboe/flute	84		
	In front of brass		91	
	Next to piccolo			91

4. ESTIMATE OF WEEKLY NOISE EXPOSURE

Combining the results of the questionnaire survey with the results of the noise survey enabled estimates to be made of typical weekly noise exposures of orchestral musicians. These estimates are based upon the typical activity times given in the questionnaire responses, as shown in Table 1. That is, it has been assumed that a typical working week consists of 22 hours of orchestral rehearsal, 7 hours of concert playing, and 11 hours of other musical activities. Several additional assumptions have been made in the calculation of weekly exposure level. The noise level for rehearsal activity is assumed to be the mean level quoted in Table 3. (Where there is no measured data for a particular music type for a particular instrument, a level has been extrapolated from the measured data.)

Some of the rehearsal sessions consisted of playing the pieces 'straight through' without a break. The levels measured during these sessions are assumed to be representative of the levels that would be measured in an actual performance. Comparison of the levels measured both for individual instruments, and at the conductor's position, during 'straight through' and 'rehearsal' playing have shown that the 'straight through' levels are 4 dB(A) higher, on average, that the rehearsal levels. Thus, the activity levels for concert playing are assumed to be 4 dB(A) higher than the mean rehearsal levels for all instruments. No noise exposure data is available for 'other musical activities', so the noise levels for these activity periods are taken to be the same as those measured

for 'light' music rehearsal activity. It has also been assumed that, out of the total rehearsal and concert time, a third of the time is spent playing each type of music.

With all these assumptions, the calculated typical weekly personal noise exposure levels for different instruments are as shown in Table 6. Note that for some instruments (cello, flute, clarinet, French horn) there was little available measured data, so these results may not be representative.

Table 6. Estimated weekly exposure levels, dB $L_{EP,w}$

Instrument	$L_{EP,w}$
Violin	90
Viola	92
Cello	89
Double bass	90
Bassoon	92
Clarinet	96
Flute	94
Oboe	90
French horn	94
Trombone	93
Trumpet	97

It is recognised that the figures in Table 6 are based upon many assumptions, chosen to represent an 'average' scenario. It is likely that the actual noise exposure levels will vary considerably day to day, or week to week, from those given in Table 6.

Nevertheless, it should be noted that, based upon these figures, the weekly noise exposures of all players, except the cellists, exceed the second action level of the UK Noise at Work Regulations, and the levels known to cause a risk to hearing.

5. CONCLUSIONS

The subjective views of members of a large symphony orchestra with regard to noise exposure and potential damage to hearing have been obtained by use of a questionnaire. A high proportion of respondents felt that they were exposed to high levels within the orchestra, mainly from other instruments. The trumpet, trombone, timpani and piccolo were commonly cited as causing high sound levels. The use of plastic screens was by far the most popular choice as a potential noise mitigation measure within the orchestra. However, a single comparison of noise exposure levels measured with and without a noise attenuating shield suggest that the screen provides no significant attenuation of the sound.

A survey of noise exposure levels during rehearsals has shown that many players are exposed to noise levels known to cause a risk to hearing. Players in the brass section have the highest noise exposures, in terms of both rehearsal activity levels and peak levels. It appears from the measurements that the noise exposure levels of individual players depend upon the type of music being played, and are not related to the position of a player in relation to other instruments. A general conclusion that can be drawn is that, for most orchestral players, the major cause of noise exposure appears to be their own instrument, rather than other instruments in the orchestra.

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