ASSESSMENT OF AN ACOUSTIC SCREEN USED FOR SOUND EXPOSURE MANAGEMENT IN A PROFESSIONAL ORCHESTRA

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It has been shown that orchestral musicians risk damage to their hearing from workplace noise exposure. Personal, administrative and engineered control measures strive to reduce exposure to the musicians while having minimal impact on the musicians' ability to produce music to the highest standard. Acoustic screens form part of a range of controls used to manage sound exposure, but their construction and placement needs to be carefully considered in the orchestral setting. Existing acoustic screens for use in orchestras have been shown to be ineffectual, to exacerbate risk of injury to some players through qualitative and quantitative changes to the acoustic environment or suffer other practical limitations such as obscuring sight lines. This study reports on an acoustic screen currently in use designed to protect musicians in front of high volume instruments while having minimal impact on players of these high volume instruments through the use of appropriately arranged diffusive and reflective materials. Sound level testing was carried out with the screens in various positions in the orchestra pit with both pink noise and high level instruments used as a sound source. Additionally sound levels were monitored during orchestral performances to assess the impact of the screens on actual exposure levels. Results indicate the screens effectively reduce exposure to those in front of high-level instruments while having a negligible impact on those producing these high sound levels.

INTRODUCTION

Orchestral musicians are at risk of noise induced hearing loss, with the level of risk they face dependent upon instrument played, repertoire and venue [1,2]. Those most exposed are musicians who work in the orchestra pit, most particularly the members of the brass section [2,3].

While it has been shown in several studies that brass players are significantly more exposed than the musicians around or in front of them (unless in extremely close proximity) those directly in front are clearly at some degree of risk from the output of the brass section. In addition these players also experience high levels of discomfort and anxiety when the brass section is playing at high volume [1-3].

There are a wide range of sound exposure control measures currently in use in Australia's orchestras, which include education programs, administrative controls and personal protective devices [4]. Engineered controls such as risers, orchestral layout and acoustic screens are also an important tool in any orchestral hearing conservation strategy but need to be approached with care. Orchestras often use large perpendicular sheets of Perspex arranged in front of the brass (often also used to shield musicians from the drum kit during 'fusion' performances involving pop/rock bands and orchestras) and/or provide personal screens made from various materials for individual musicians. These include single sheets of Perspex mounted on a stand, wrap-around absorptive screens also mounted on stands and also screens that attach to the musicians' chair and adjust with the player's position.

As practicing orchestral musicians devising and operating hearing conservation strategies, two authors of the current paper have identified several issues that frequently arise with the use and effectiveness of orchestral acoustic screens, some of which have been verified in the limited literature on the topic. Arrangement of large sheets of reflective material in front of highly directional instruments such as the brass reflects sound back to the musicians already at high-risk, increasing their sound exposure and producing significantly deleterious qualitative changes to the acoustic for these musicians. Libera and Mace [5] demonstrated small Perspex personal screens were relatively ineffective as protective devices due to a number of factors, including difficulty positioning the screens due to movement of the musicians and the necessity for very close proximity to the protected ear in order to effectively attenuate sound levels. Williams and Stewart [6] subsequently showed that these screens could increase sound levels by reflection for those musicians playing into them by as much as 3dB, effectively doubling these musicians' sound exposure. More absorptive screens have been shown to be effective as a protective device [6] and are an important tool for orchestras, but have been observed by the authors to be difficult for players of certain instruments to position effectively, often due to restriction of movement while playing – particularly for instruments such as upper strings and trombones. Further to this, when used by several players in a row these screens can create a large absorptive surface within the orchestra. Such a surface in close proximity to the musicians may cause the brass sound to lack power and potentially cause strain injuries as these players strive to project their sound to the conductor's podium and into the auditorium.

In addition to these concerns, any screen or other visual interference placed in front of musicians can cause problems with sight lines to the conductor and effectively isolate these musicians from the rest of the orchestra. To the knowledge of the authors there are no purpose-built orchestral acoustic screens effectively addressing these issues.

A potential solution is to create an acoustic screen using a combination of diffusion and reflection. Diffusion can be used to disperse sound and avoid reflection directly back to the players, while any directly reflective surfaces can use incident angles to also avoid significant reflection of the sound back to the musicians creating it and project sound out of the orchestra pit and into the auditorium.

The Queensland Symphony Orchestra (QSO) has one of Australia's most active and effective hearing conservation programs [4] and as such has been developing solutions to problems with orchestral screens for several years. Recently improvements were made to some of their bespoke acoustic screens in order to address issues players had been having seeing the conductor and the opportunity arose to test their effectiveness in situ.

The aim of this investigation was to determine whether a purpose-built acoustic screen in use in an orchestra pit was effective at mitigating sound exposure while having limited impact on those musicians creating the high sound levels.

METHOD

The orchestral screens (Figures 1 and 2) are built from light timber with metal legs and Perspex panels.

The base consists of simple variable depth vertical panels (75 mm wide, 35 to 150 mm in depth) while the top section consists of a sheet of Perspex in a supported frame, capable of being angled to suit various situations. This top section has a long (800 mm) or short (400 mm) option, depending upon the nature of protection needed and visual practicability (sight lines to the conductor).

In order to gather data on attenuation, two orchestral trumpet players were recruited on a voluntary basis from the orchestra and undertook testing during a break in the opera being rehearsed at the time. The musicians were instructed to play a short duet (around a minute in length) several times at a 'loud' volume direction (*forte*) in their normal seated position within the orchestra pit.

Three Type 1 data-logging sound level meters (Casella CEL632) were set on stands, one at the chair of the musician directly in front of the trumpets at approximately ear level when seated (1260 mm), the other two within 100 mm of each trumpeter's right ear (Figure 3). The units were calibrated using a matching calibrator directly prior to the assessment. The entire testing session was recorded without adjustment and results were later analysed using proprietary software associated with the sound level meters (*CEL Insight*).

In total four setups were trialled:

1. Screen in place with long top section
2. Screen in place with short top section
3. Screen in place with no top section
4. Screen removed altogether

The musicians played the duet three times for each configuration and were instructed to ensure each performance of the excerpt was as close as possible in volume and tone. Each set of three performances were averaged (using the arithmetic mean) to reduce the impact of any individual variation by the players.

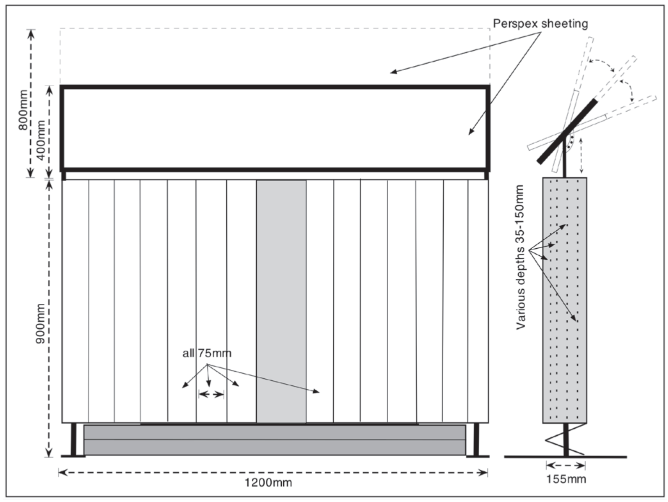

Figure 1. Illustration of diffusive/refractive orchestral acoustic screens

Figure 2. Orchestral acoustic screens setup for ballet rehearsal (short screen in place)

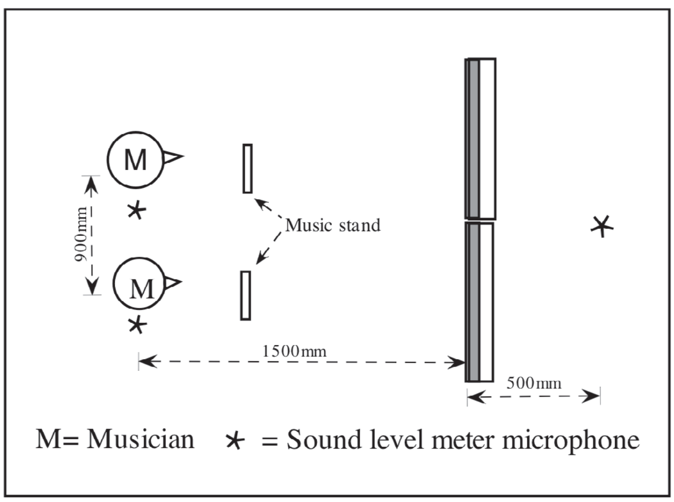

Figure 3. Illustration of recording method

In addition, a series of recordings were made in the four setups above using a loudspeaker positioned in the first trumpet position at seated head height delivering pink noise at approximately 80dBA. The pink noise was generated using the software 'Noisy' (version 1.2, produced by 'Noisy Developers', 2010) running on a laptop computer. The output level was calibrated using a CEL460 dosimeter in sound level meter mode, with its microphone positioned 100 mm in front of the speaker.

Sound exposure to orchestral musicians is a complex phenomenon involving acoustics, orchestral set-up, repertoire, direct sound from the instrument played as well as sound from adjacent musicians. As such a series of measures were also taken with the screens in place during complete orchestral performances to determine whether attenuation levels observed during the controlled investigation were maintained when many sound sources were present, including that of the 'protected' musician. These results were then compared to data from a previous study of sound exposure in this orchestra [2] prior to the introduction of the acoustic screens being investigated, ensuring orchestra size, instrument, orchestral set-up and venue were replicated.

All of these 'real-orchestra' measures were taken as part of the QSO's ongoing noise monitoring program with procedures that have remained unchanged since the program commenced in 2004. Three CEL460 dosimeters were used, calibrated prior to and at the conclusion of each measurement. These were mounted on boom microphone stands in each instance, with the microphone positioned at ear level <30cm from the ear.

Throughout this report data is presented in dBC peak and dBALEQ, with the latter representing the equivalent steady state A-weighted sound level required to replicate the expended energy of the actual (fluctuating) measured exposure over the period of the assessment.

RESULTS

The configuration with the greatest effective attenuation for either dBA or dBC peak levels for both sound sources was with the longer Perspex screen deployed (Tables 1, 2 and 3). With the trumpets as a sound source the greatest difference between the first trumpet and the screened position was 10.4 dBALEQ and 10.2 dBC peak. With pink noise as a sound source the greatest difference recorded was 20.4 dBALEQ between the pink noise generating speaker and the screened position. This reduction in level includes the effect of distance from the sound source, so in order to highlight the effect the screen had on sound levels in the screened positions, the difference between the unscreened levels at the 'exposed' position and the various screened levels has also been detailed in Tables 1 to 3, with the greatest effective attenuation of 4.1 dBLEQ and 5.3 dBC peak.

Table 1. Sound source – trumpet duet, various screen positions. The duet was played three times in each position with results for each set of three arithmetically averaged (the range of this data is indicated in brackets). All data is presented in dBALEQ

Position	No Screen	Base Only	Short Screen	Long Screen
Trumpet 1 right ear (range)	103.6 (0.6)	103.3 (0.5)	103.3 (1.4)	102.3 (1.4)
Trumpet 2 right ear (range)	101.1 (0.2)	100.6 (0.4)	100.9 (0.6)	101.2 (0.8)
Screened position (range)	97.3 (0.3)	96.7 (0.3)	93.6 (0.5)	91.9 (0.5)
Difference between trumpet 1 and screened position	6.3	6.6	9.7	10.4
Effective attenuation by screen	--	0.3	3.4	4.1

Table 2. Sound source – trumpet duet, various screen positions. Peak readings for each setting. Highest recorded peak for each setting is reported. All data is presented in dBC

Position	No Screen	Base Only	Short Screen	Long Screen
Trumpet 1 right ear (range)	118.8	118.4	118.6	118.3
Trumpet 2 right ear (range)	118.7	118.6	118.7	117.8
In front of screen	113.9	112.8	110.0	108.1
Difference between trumpet 1 and screened position	4.9	5.6	8.6	10.2
Effective attenuation by screen	--	0.7	3.7	5.3

Table 3. Sound source - pink noise at 80 dBA, various screen positions. All data is presented in dBALEQ. (* positioned slightly behind the sound source)

Position	No Screen	Base Only	Short Screen	Long Screen
Reference microphone	80	80	80	80
Trumpet 1 position*	72	72.1	72.1	72.2
Trumpet 2 position*	67.8	67.9	68.1	67.9
Screened position	65.4	65.2	61.1	59.6
Difference between reference and screened position	14.6	14.8	18.9	20.4
Effective attenuation by screen	--	0.2	4.3	5.8

In any of the three screen configurations there was no appreciable increase in sound level (dBC peak or dBALEQ) observed to the trumpet 1 or 2 positions compared to readings taken without the screens in place.

As a significant contributor to sound exposure amongst many orchestral musicians is direct sound from their own instrument in addition to sound from adjacent instruments [1,2], further readings were taken during two orchestral opera and ballet performances to determine whether attenuation levels noted in the experimental set-up were similarly evident with the entire orchestra present. Results of these readings are presented in Table 4 together with levels recorded during a performance with no acoustic screen present.

DISCUSSION

In order to determine the effectiveness of bespoke acoustic screens designed for use in an orchestra pit, sound levels were measured with two trumpet players playing a short, relatively loud duet with the screens either removed altogether or in various configurations. These measurements were then repeated using pink noise at 80 dBA as a sound source. To verify these results and explore exposure levels during actual performances, sound levels were also monitored during opera and ballet performances and compared with previously published data at these points from the same orchestra in an identical pit set-up without an acoustic screen present [2].

Results showed the screens are effective at reducing sound exposure without increasing exposure to the musicians 'upstream'. The screens are most effective while configured with a longer upper panel, however as this causes visual interference between the brass section and the conductor it is not ideal. As use of the smaller upper panel still provides adequate protection for the musician in front of the screen this has been chosen as the preferred option in the orchestra pit during performances.

An important factor in the reduction of sound levels is the distance between the sound source and the individual/s requiring protection. This distance alone significantly reduces the intensity of sound reaching those in front as seen in the column labeled 'No Screen' in Tables 1-3. In this case, with no screen present the two meters between the trumpet 1 position and the 'exposed' position effectively attenuated the sound level by 6.3 dB, accounting for a 75% reduction in sound exposure consistent with fundamental acoustic principles. This emphasises the crucial role distance plays in an orchestra as an exposure control measure. When developing hearing conservation strategies or proposing orchestra and band layouts, the combination of effective acoustic screens with distance is a very powerful tool in sound level reduction.

To more clearly illustrate the impact this level of sound attenuation has during an actual performance, Table 5 details expected levels in front of the screen based upon sound exposure at the right ear of cello 6 (rear desk) as reported in Table 4. Allowable recommended noise exposure is based upon 85 dBALEQ for eight hours, with an exchange rate of 3 dB. As players are often required to perform twice in one day (with performances up to and sometimes beyond 180 minutes in length) it appears the use of this screen with either a low or full screen would allow those protected to perform without the need for personal hearing protection.

Compared to previous investigations the screens have been shown to be at least as effective as the individual wrap-around absorptive screens used in orchestras (reported as 8 dB one metre from the sound source using pink noise [6]) and more effective than various configurations of single Perspex sheets reported by Libera and Mace [5] with few of the difficulties noted when either of these individual screens are utilised.

The screens have been also reported to be effective beyond the orchestra pit when a drum kit is placed within or close to the orchestra, to protect musicians from loud cymbal crashes. In this instance the screens are deployed with the Perspex angled away from the drummer and the diffusive panels facing towards the drummer. Anecdotally, drummers employed with the orchestra have reported a preference for these screens over the simple perpendicular Perspex sheeting, citing a greater comfort, much less reflection of their own sound back to them and greater connection with the ensemble.

Additionally, the screens are regularly deployed around two meters behind the French horn section with the Perspex angled away from the musicians in venues where there is either absorptive material to the rear of the stage or a very deep stage. Horn players report greater ease of projection and less need to play at extreme volume with the screens in place. Horn players had also been using perpendicular Perspex sheeting for this purpose prior to the

Table 4. Sound exposure during opera and ballet performances, various screen positions. All data is presented in dBALEQ

Position	No Screen (ballet)	Short Screen (ballet)	Long Screen (opera)
Trumpet 1	90.1	91.4	90.1
Cello 6	89.1	85.4	82.9
Difference between trumpet 1 and screened position	1.0	6.0	7.2

Table 5. Measured exposure and time to reach allowable recommended noise exposure in front of acoustic screen based on exposure reported in Table 4

	No Screen (ballet)	Short Screen (ballet)	Long Screen (opera)
Measured exposure in front of screen - cello (dBALEQ)	89.1	85.4	82.9
Time to reach recommended allowable noise exposure (minutes)	186	438	780

introduction of the screens and report greater aural comfort when playing at high volume with the bespoke screens.

This study was limited in that only one orchestral configuration within a single venue is presented. As previously reported, orchestral sound exposure is highly variable according to repertoire, instrument played, venue and orchestral configuration [2]. As such the effect of placing the described screens in alternate positions within the orchestra is still a matter of speculation. It is possible, for example, that the placement of instruments producing significantly higher sound levels in front of these screens may exacerbate exposure levels to these musicians. This requires further investigation.

CONCLUSIONS

The acoustic screens described and investigated in this study were developed in the field over several years. They are a flexible and useful addition to hearing conservation control measures within a typical orchestra when used in the context of a detailed hearing conservation strategy. They both increase comfort and significantly reduce risk for those in need of protection from louder instruments to the rear without increasing the risk or discomfort to players of these louder instruments who have amongst the highest risk of overexposure to sound of any in the orchestra.

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