

Musicians' hearing protection

A review

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The music and entertainment industry is unique in that high noise levels are often regarded as an essential element for the enjoyment of people attending concerts and live music events. However, there is a risk of hearing damage for people working in the music and entertainment industry, including musicians. One of the methods used to reduce noise exposure is the use of appropriate hearing protection. Many different types of hearing protection have been marketed for musicians including premoulded earplugs, custom-moulded earplugs and in-ear monitors. In order to support the Health and Safety Executive's (HSE) understanding of this issue, the types of hearing protection available to musicians were identified. Telephone interviews were then conducted with nineteen professional musicians to collect information on: the type of hearing protection (if any) musicians are currently using; musicians' attitudes to hearing protection including whether they think it is, or it can be, effective and whether it allows them to do their job effectively; and the factors musicians consider important when choosing hearing protection.

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EXECUTIVE SUMMARY

Objectives

The music and entertainment industry is unique in that high noise levels are often regarded as an essential element for the enjoyment of people attending concerts and live music events. However, there is a risk of hearing damage for people working in the music and entertainment industry, including musicians. One of the methods used to reduce noise exposure is the use of appropriate hearing protection. Many different types of hearing protection have been marketed for musicians including premoulded earplugs, custom-moulded earplugs and in-ear monitors. In order to support the Health and Safety Executive's (HSE) understanding of this issue, the types of hearing protection available to musicians were identified. Telephone interviews were then conducted with nineteen professional musicians to collect information on: the type of hearing protection (if any) musicians are currently using; musicians' attitudes to hearing protection including whether they think it is, or it can be, effective and whether it allows them to do their job effectively; and the factors musicians consider important when choosing hearing protection.

Main Findings

Semi-structured telephone interviews were conducted with nineteen musicians between June and October 2007 to gain an understanding of their attitude towards using hearing protection, and on the performance and usability of available hearing protectors. Although the sample was small it was well represented across the different types of instruments played, how long the musicians had played professionally, and the range of work experiences. The majority interviewed were classical musicians playing in large orchestras. However, the views of three freelance percussionists and two military band players provided some insight into the experiences of other types of musicians playing different styles of music and in different venues.

The findings presented in this report were obtained from telephone interviews with musicians and from discussions with, and information provided by, hearing protector manufacturers and suppliers.

Musicians most commonly use conventional foam and flange earplugs because they are easy to fit during a performance, and they are often the most readily available. However conventional protectors can provide too much protection when fitted properly, and they can cause musicians to mishear or overplay as a result of the lack of high frequency sound heard through the protectors. Musicians are most likely to wear conventional hearing protectors when they are exposed to very loud music generated by other musicians.

Premoulded musicians' earplugs provide moderate attenuation but preserve sound quality. They are a relatively inexpensive off-the-shelf earplug, and are reusable if kept clean. They can improve sound quality for those musicians working with or around amplified sound.

Custom-moulded musicians' earplugs use interchangeable filters to provide different levels of protection (9 - 25 dB), and have been designed to preserve a natural sound quality. They are expensive and difficult to fit, but they are also unobtrusive if aesthetics are an issue. Despite improved sound quality, orchestral musicians do not believe they can play properly when

wearing custom-moulded protectors. However they are more likely to use this type of protector when listening to other musicians.

Musicians are reluctant to wear any type of hearing protection when playing solo or exposed pieces of music, which require them to play at the highest possible standard. Principal musicians, and woodwind and brass musicians are likely to be the most resistant to wearing hearing protection.

Custom-moulded vented earplugs are available, which are designed to provide significant high frequency attenuation and very little low frequency attenuation. A hole through the length of the earplug reduces the occlusion effect. These earplugs may be useful for musicians who play low frequency instruments, and for those who blow into their instrument (eg woodwind and brass players). However none of the musicians interviewed for this study were aware of, or used, custom-moulded vented earplugs.

In-ear monitors provide musicians with a method for controlling the level of incoming sound when used with a personal mixing desk, and the earpiece provides some isolation. There are currently no standard tests for governing the performance of custom-moulded electronic earplugs.

A range of noise control methods other than hearing protectors is available for reducing musicians' noise exposure. These include the use of screens and risers, regularly rotating musicians within the orchestra, increasing the separation between players, and sound limiting on electronic systems. However reflected sound makes the use of screens unpopular, and the lack of space in many orchestra pits and studios can make it difficult to implement many of the other control measures.

Recommendations

It is essential that suitably qualified professionals take and manufacture all ear-moulds to a high standard. Poor ear-moulds can result in earplugs that are uncomfortable, or that block out too much sound, and which are therefore unlikely to be used.

Musicians should ensure that the hearing protectors they use are CE marked and supplied with attenuation data according to BS EN 352, which describes and verifies the performance of the protector.

A good education programme is needed for both employed and self-employed musicians. It should include information on the requirements of current noise legislation clearly identifying employer's and employee's responsibilities, typical noise exposures and the associated risk to hearing, the signs and symptoms indicative of hearing damage, and the types of hearing protectors available and the advantages and disadvantages of each type.

Training on the selection and proper use of hearing protection is also essential to ensure that the use of hearing protectors is an effective measure for controlling musicians' noise exposure. Musicians need wear earplugs during rehearsals and performances so that, with time, they hear the attenuated music as normal, especially with musicians' earplugs that are designed to preserve sound quality. If earplugs are worn throughout a performance the fact that they are difficult to fit, or that fitting them during a performance spoils the continuity of the music for the musician, will no longer be a problem.

It is essential that methods used to control noise be given consideration when designing or refurbishing venues in which live music is played, so that musicians do not have to rely on hearing protection.

1 INTRODUCTION

The music and entertainment industry is unique in that high noise levels are often regarded as an essential element for the enjoyment of people attending concerts and live music events. However, there is a risk of hearing damage for people working in the music and entertainment industry, including musicians. An earlier literature search was carried out according to the search strategy described in Appendix A to investigate musicians' noise exposure. The results of this search showed that orchestral musicians can be exposed to A-weighted continuous noise levels between 80 and 110 dB and rock/pop musicians can be exposed to A-weighted noise levels between 88 and 117 dB. Appendix B contains a summary of this review.

Many studies have been carried out to identify whether there is a link between musicians' noise exposure and the incidence of hearing loss among musicians. A review of published studies is contained in Appendix C. It is very difficult to draw conclusions about the incidence of hearing damage among both classical and rock/pop musicians because of the conflicting conclusions drawn from the different studies. Eight of the studies concluded that there was no significant difference between the hearing threshold levels of musicians and non-noise exposed reference populations; two found musicians with better hearing than the reference population; and six concluded that musicians have slightly poorer hearing thresholds than non-noise exposed reference populations. Poor study design may be responsible for some of the conflicting conclusions. Nevertheless the reported evidence suggests that musicians' noise exposure may be high enough to cause some hearing loss and to increase the incidence of hearing disorders such as tinnitus and hyperacusis.

The Control of Noise at Work Regulations 2005, which are designed to prevent hearing damage, cover all employees working in the music and entertainment industry. Employers have a duty under this legislation to protect the hearing of their employees. One of the methods used for reducing and controlling noise exposure is use of appropriate hearing protection. Its use should only be considered as a last resort or where it is not reasonably practicable to control exposure by other means. Many different types of hearing protection have been marketed for musicians including premoulded earplugs, custom-moulded earplugs and in-ear monitors.

In order to support HSE's aim of preventing hearing damage among musicians, a project was carried out with the following objectives:

- To identify the types of hearing protection currently available to musicians;
- To carry out telephone interviews with 10-15 professional musicians to collect information on:
 - the type of hearing protection (if any) musicians are currently using;
 - musicians' attitudes to hearing protection including whether they think it is, or it can be, effective and whether it allows them to do their job effectively; and
 - the factors musicians consider important when choosing hearing protection, eg comfort, attenuation (ie noise reduction) requirements, and quality of attenuated music and speech.

2 HEARING PROTECTOR TYPES

This section briefly describes the wide range of hearing protectors that are generally available. Further information can be found in BS EN 458: 2004 and in Controlling Noise at Work: The Control of Noise at Work Regulations 2005 (HSE, L108). The advantages and disadvantage of each type of protector are described, and where appropriate the usefulness of the protector for musicians is identified.

2.1 EARMUFFS

Earmuffs consist of hard plastic cups, which fit over and surround the ears. The cups are sealed to the head by cushion seals usually filled with soft plastic foam or a viscous fluid. Tension to assist the seal is provided by a headband. The inner surfaces of the cups are lined with a sound-absorbing material, usually soft plastic foam.

Earmuffs are generally cheap and easy to use, they can provide high levels of protection in high noise environments when worn correctly, and the occlusion effect is less significant compared with earplugs, especially for earmuffs with large (high-volume) cups. [Note: The occlusion effect occurs when the ear canal is blocked which causes sound to be reflected back towards the eardrum. The occlusion effect increases the loudness perception of a person's own voice and can boost low frequency noise in the ear canal.]

The disadvantages associated with using earmuffs are that they are heavier and more obtrusive than earplugs, they typically provide higher levels of attenuation at high frequencies than low frequencies, they can be uncomfortable in hot, humid conditions, and their effectiveness can be compromised when the seal is broken by glasses, jewellery, long hair and facial hair.

2.2 EARPLUGS

Earplugs are hearing protectors that are inserted and worn in, or which cover, the ear canal in order to seal its entrance. They can be disposable or reusable, and are available in many different forms. Figure 1 shows a selection of earplugs. Earplugs may not be suitable for all wearers because of medical conditions.



Figure 1: Earplugs

2.2.1 User formable earplugs

These are made from compressible materials that the wearer forms before inserting them into the ear canal. After insertion, these earplugs expand to form a seal within the ear canal. The advantages of user formable earplugs are that they are cheap, they can effectively protect against high noise levels, they are portable being small enough to carry around in a pocket, and they are more comfortable in hot environments than earmuffs.

One of the main disadvantages of earplugs, especially user formable plugs, is that they can be difficult to fit properly. Training on how to fit earplugs is essential, because they can offer virtually no protection when fitted incorrectly. Other disadvantages include uneven attenuation characteristics, which “colour” the sound so that it no longer sounds natural (for example a foam earplug that reduces low frequency sounds by 20 dB, may reduce high frequency sounds by 40 dB), the occlusion effect which distorts sound perception, and there is a risk of infection if earplugs are inserted with dirty hands.

Published literature suggests that conventional user formable earplugs may not be suitable for vocalists and musicians, especially for those who play brass and woodwind instruments because of the occlusion effect.

2.2.2 Premoulded earplugs

These are usually made from silicone, rubber or plastics, and are available in a range of different shapes including flanged (ie Christmas tree) and domed (ie toadstool). They may also be available in a range of sizes. This type of earplug is designed to enable easy insertion into the ear canal without the need for shaping. Premoulded earplugs are generally reusable, but they require regular cleaning.

2.2.3 Custom-moulded earplugs

Qualified professionals individually mould these earplugs to fit the shape of the user’s ear canal. Figure 2 shows examples of custom-moulded earplugs. These moulds can be fitted with filters that shape the sound heard by the wearer, in-ear monitors for use with amplified music systems, and communication devices. It is essential that suitably qualified people make custom ear-moulds as poor ear-moulds are likely to be uncomfortable and compromise the performance of the resultant device.



Figure 2: Custom-moulded earplugs

2.3 SOUND RESTORATION LEVEL-DEPENDENT HEARING PROTECTORS

These incorporate an electronic sound reproduction system. At low levels the noise detected by an external microphone is relayed and amplified to a loudspeaker inside the hearing protector. As the external noise level increases, the electronics gradually reduce the amount of noise transmitted to the inside of the hearing protector.

Sound restoration level-dependent hearing protectors may be suitable for musicians playing instruments with a large dynamic range, such as brass, woodwind and percussion. It is particularly important for brass and woodwind players to have negligible attenuation at lower noise levels because they have significant skull contact with their instruments. This means that their ears receive both the treble-rich (high frequency) noise via the eardrum and bass-rich (low frequency) noise via bone conduction. When the eardrum noise is reduced, for example due to the use of hearing protectors, the bass-treble distortion can be significant.

2.4 FLAT OR TAILORED FREQUENCY RESPONSE HEARING PROTECTORS

Most hearing protectors provide greater attenuation for high frequency noise than for low frequency noise. Flat frequency response hearing protectors are designed to give a similar reduction across a wide range of frequencies, which results in a more natural sound.

2.5 HEARING PROTECTORS WITH IN-BUILT COMMUNICATION SYSTEMS

These devices use a wired or wireless system through which working signals, alarms, messages or entertainment programmes can be relayed. Some products incorporate a system to limit sound.

Musicians, vocalists and sound engineers commonly use headphone monitors, which can incorporate a combination of active and passive attenuation as well as signal limiters. Only headphones incorporated into an earmuff complying with BS EN 352-6 (and BS EN 352-1) are designed and approved to provide noise attenuation in noisy environments.

3 HEARING PROTECTORS FOR MUSICIANS

The following sections contain information on factors that are likely to be important to musicians when deciding to wear, and selecting suitable, hearing protection. A range of hearing protectors is also described that have been specifically designed with the needs of music and entertainment industry professionals in mind.

3.1 NOISE ATTENUATION

Musicians need to hear while they play, both their own music and that of other players. Conventional hearing protectors can often provide too much attenuation for this purpose, as well as having a detrimental effect on the sound quality heard by the user. A reduction of less than 10 dB is often sufficient for musicians, however conventional hearing protectors often provide significantly more than this and using them might result in mishearing or overplaying. The overall attenuation provided by musicians' earplugs is designed to avoid unnecessarily high protection in moderate noise. These protectors typically offer a range of protection from 9 to 25 dB. [Note: The protection provided by some low attenuation earplugs does not meet the minimum attenuation requirements specified by BS EN 352-2: 2002, and these protectors do not therefore carry the CE mark.]

3.2 ATTENUATION CHARACTERISTICS

Inserting an earplug into the ear removes the ear's natural resonant peak (approximately 15 dB at 2.7 kHz in the average ear) (Niquette, 2006). This insertion loss causes music and voices to sound muffled. The attenuation characteristics of conventional earplugs can also make it difficult for the wearer to hear music and speech clearly; they typically provide more attenuation at higher frequencies than in the mid and lower frequencies. Most musical instruments have a significant amount of energy above 1 kHz, with harmonics that are more intense than the fundamental frequency. These high frequency harmonics are vital for accurate loudness perception, and they also contribute to the richness of the music. Earplugs that provide high levels of high frequency attenuation can have a detrimental effect on the tonal balance of the music, as perceived by the wearer. This can result in mishearing or overplaying to compensate for the lack of high frequency sound heard through the earplugs.

Earplugs are commercially available with attenuation characteristics that follow the shape of the natural frequency response of the open ear, but at a reduced level. These earplugs are designed so that sound heard with the earplugs fitted has the same quality as the original sound, but it is quieter. This type of device is available as both a premoulded earplug and a custom-moulded earplug.

3.3 OCCLUSION EFFECT

Occluding and sealing the ear with an earmuff or earplug (Berger, 1988) increases the efficiency with which bone-conducted sound is transmitted at frequencies below 2 kHz. This is called the occlusion effect. When a musician sings or blows into the mouthpiece of an instrument, the sound is transmitted via the jaw to the bone surrounding the inner portion of the ear canal. Blocking the ear canal with an earmuff or earplug allows this noise, which is effectively generated within the ear canal, to build up within the enclosed space. This causes an increase in the sound pressure level at the eardrum in the occluded ear compared to the open ear for sounds generated by the user (eg vocalist, brass or woodwinds). Compared to a completely open ear canal, the occlusion effect may boost low frequency (usually below 500 Hz) sound pressure in the ear canal by more than 20 dB.

The occlusion effect causes wearers of hearing protectors to experience a change in the perception of their voice quality and other body-generated sounds and vibrations (eg breathing, chewing, etc). In addition, some people may also feel a sense of pressure or blockage in the ear when an earplug is inserted.

There are two ways to reduce or remove the occlusion effect (Ross, 2004). The most effective way is to not completely block the ear canal with an ear-mould, by creating a vent hole that connects the outer surface of the earplug to the inner surface. This permits the bone-conducted sound generated in the ear canal to escape the ear in the way that it is supposed to. The amount of sound that escapes, and therefore the magnitude of the occlusion effect, depends on the size of the vent. The larger the vent, the more the occlusion effect can be reduced.

Another method of reducing the occlusion effect is to use a very long and tight ear-mould (Killion, 2003); the plug should make a seal in the second bend of the ear canal (deep in the ear canal). The presence of the ear-mould deep in the ear canal prevents the sound vibrations produced by the wearer from being developed. However care is needed because a tight-fitting ear-mould situated deep in the ear canal may be uncomfortable and irritate the skin in the ear canal.

3.4 COMMERCIALLY AVAILABLE MUSICIANS' HEARING PROTECTION

3.4.1 Custom-moulded flat response earplugs

The flat frequency response custom-moulded earplugs designed for use by musicians use a patented filter with the specific acoustics of a custom ear-mould (Killion, 1993, 2004). The filter contains a thin plastic diaphragm that functions as an acoustic capacitance, while the volume of air in the sound bore of the ear-mould acts as an acoustic mass. Figure 3 is a diagram of a musician's earplug.

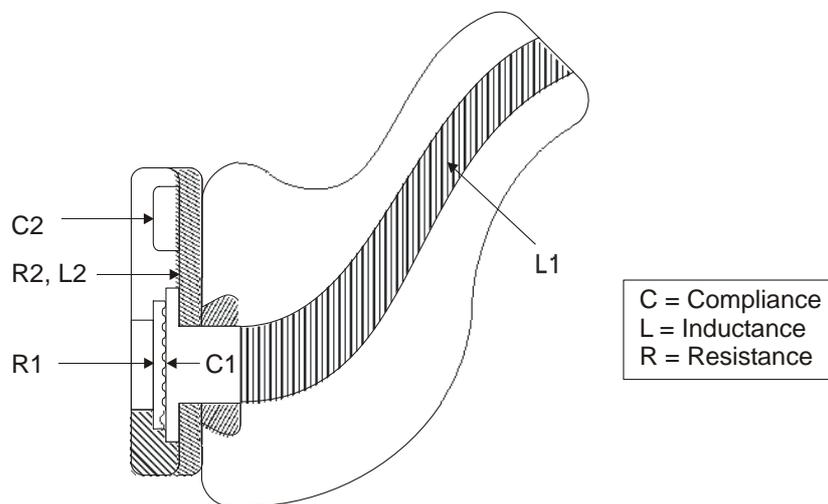


Figure 3: Musician's earplug (Killion, 1993)

The combination of the filter and the volume of air produces a resonance at approximately 2.7 kHz (as in the open ear) resulting in attenuation characteristics that follow the natural frequency response of the open ear, but at a reduced level, between 80 Hz and 16 kHz. Increasing the diaphragm stiffness increases the attenuation provided by the earplug, and several different levels of attenuation are available for a range of uses:

- Earplugs are available that attenuate low frequencies by 9 dB and attenuate high frequencies by up to 15 dB (low attenuation devices).
- Earplugs that provide 15 dB attenuation are available (medium attenuation devices). Music heard through these earplugs retains the same quality as the original, only quieter. These are designed for environments where the A-weighted sound pressure level is 105 dB(A) or lower.
- Earplugs providing a near uniform 25 dB attenuation (high attenuation) were developed for musicians exposed to high levels of noise (eg drummers and rock musicians). These are designed for use in environments above 105 dB(A) and below 120 dB(A).

Custom-moulded earplugs are manufactured to fit individual ears, and are claimed to give repeatable performance, consistent protection and increased comfort for longer periods of time. They are available in a variety of medical-grade silicone and vinyl materials to reduce irritation of sensitive ears; flesh coloured earplugs are an option, which are unobtrusive and in some situations highly desirable. A range of interchangeable filters (9, 15 and 25 dB) can be purchased, which are inserted into the custom-moulds to give the level of protection that is most suitable for the particular noise environment.

One of the disadvantages of custom-moulded earplugs is that they are expensive. However they are designed to give several years of reliable use, and long life will result in low cost per individual per day. It is essential that a qualified professional make custom-moulded earplugs. Poor ear impressions will significantly limit the effectiveness of this type of earplug (Killion, 2003). Proper maintenance is also essential to ensure that the earplugs do not damage the delicate lining of the ear canal. As with all forms of hearing protection, it is essential that training be provided on how to fit custom-moulded earplugs and how to get used to rehearsing and performing with them fitted in the ears. Custom-moulded earplugs have a shelf life of 4 to 5 years due to the aging process of the earplug material and also the change in the shape of the user's ear over this time period.

Manufacturers recommend the use of custom-moulded earplugs for musicians who play or who are located near to instruments that produce high frequency sounds, such as trumpets, pianos, violins and piccolos. They are also useful for anyone who works with or around amplified music, including musicians, vocalists, conductors, and sound engineers.

It is essential that the performance of custom-moulded musicians' earplugs is assessed and verified. They should be CE marked and attenuation data according to BS EN 352-2 should be available on request from the manufacturer or supplier. HSE recommends that fit tests are carried out before custom-moulded earplugs are put into use to ensure that they fit properly and are comfortable (HSE, L108).

3.4.2 Custom-moulded vented earplugs

Custom-moulded vented earplugs have an adjustable valve (hole) through the length of the earplug. This is designed to provide significant high frequency attenuation, but allows the lower frequency sound to pass through the earplug unattenuated (Chasin, 1992). The frequency characteristics depend on the vent diameter. In the most open position (3 mm diameter vent) these earplugs are acoustically transparent up to 2 kHz, but attenuate higher frequencies by about 20 dB. Closing the vent increases the amount of high frequency attenuation to about 28 dB. A side effect of these vented earplugs is that the mass of air in the vent resonates, which gives rise to a small amplification around 500 Hz. This can be used to improve the user's ability to monitor their voice, and might be useful for vocalists.

Custom-moulded vented earplugs are useful for musicians who play bass and lower frequency instruments (for example acoustic bass and cello). They are also useful for musicians whose instruments do not generate high noise levels (eg clarinet) but who play near other noisy instruments, such as the drums. Vented earplugs will attenuate high frequency sounds from percussion and trumpet sections, therefore allowing musicians to hear their own music. Another advantage of custom-moulded vented earplugs is that there is very little occlusion effect, provided that the ear-mould has been taken and manufactured to a high standard. As with other custom-moulded earplugs, these earplugs are expensive and need to be custom-moulded by a qualified professional.

It is essential that the performance of custom-moulded vented earplugs, including the effect of the vent, is assessed and verified. The earplugs should be CE marked and attenuation data according to BS EN 352-2 should be available on request from the manufacturer or supplier. HSE recommends that fit tests are carried out before custom-moulded earplugs are put into use to ensure that they fit properly and are comfortable (HSE, L108).

3.4.3 Premoulded musicians' earplugs

Premoulded musicians' earplugs have been developed to provide low-cost high fidelity earplugs that can be used in a variety of noisy environments. They are designed to provide moderate attenuation but preserve sound quality. This is achieved using a tuned resonator and an acoustic resistor to give relatively flat attenuation characteristics up to about 6 kHz. The vented design reduces "blocked up" feelings. They are manufactured using material that is soft, durable and non-irritating, with a triple-flange design for increased comfort during extended wear. Figure 4 shows a sketch of this type of earplug.

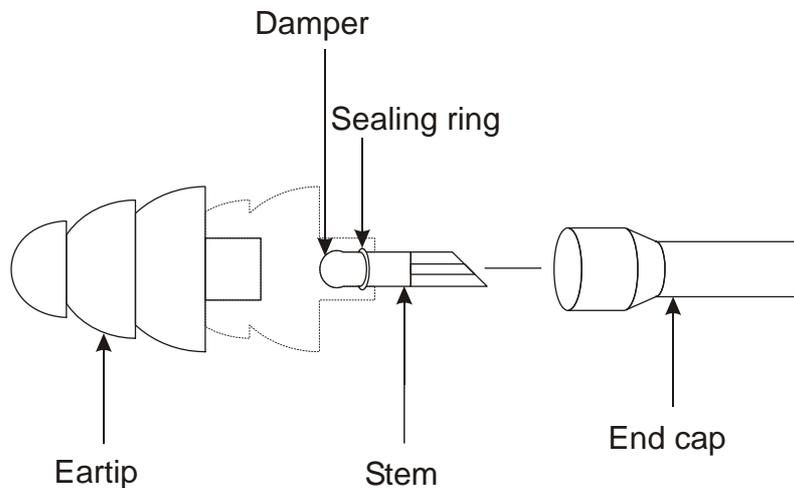


Figure 4: Premoulded musician's earplug (Killion, 1993)

The advantages of premoulded musicians' earplugs are that they are less expensive than custom-moulded earplugs, they are available off the shelf, and are reusable if kept clean. The disadvantages are that they are more expensive than user formable earplugs and the attenuation characteristics are not as flat as custom-moulded earplugs.

Premoulded earplugs are useful for musicians and vocalists looking for a relatively inexpensive flat frequency response earplug for use during practice and rehearsals.

Figure 5 compares the attenuation characteristics of the different types of musicians' earplugs with the attenuation characteristics of a conventional foam earplug. It shows clearly the different attenuation characteristics for each type of plug.

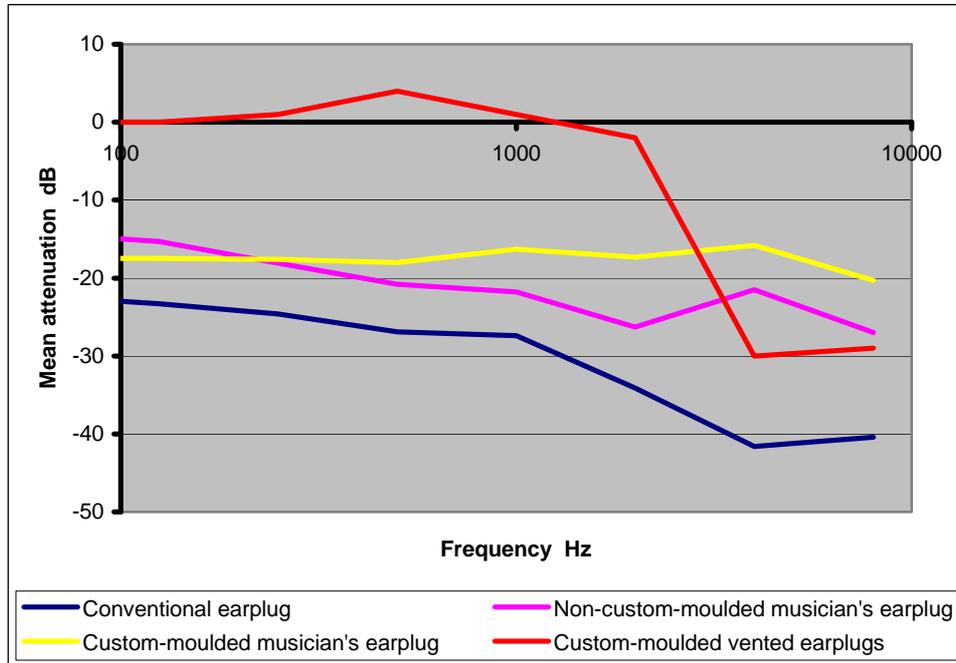


Figure 5: Attenuation characteristics for different types of earplugs

3.4.4 In-ear monitors

The purpose of on-stage monitor systems is to allow the performers to hear themselves on stage over a range of competing sound sources (Santucci, 2006). The PA system, crowd noise, on-stage amplifiers, and escalating noise levels from other musicians trying to hear themselves, all add to the difficulty in musicians hearing their own instrument or voice during a live performance. The solution has been to place loudspeakers on stage in front of the musicians, and at other locations on stage as required. With the ever-increasing size of venues and stages, more loudspeakers are needed to provide sound to all areas of the concert venue. These loudspeaker monitor systems present a variety of problems for the musicians, the audience and the sound engineers. The performers are forced to turn up the volume of their monitor loudspeakers to hear themselves over the competing sound sources, while the sound engineer is challenged to manage the resultant feedback from the loudspeakers. As a result, all on-stage personnel can be exposed to very high levels of noise.

In-ear monitoring is emerging as the preferred method of on-stage sound reinforcement for live concerts (Santucci, 1999), and in-ear monitors are replacing the stage monitor speakers traditionally used by musicians. Everything that the musician wants to hear through the in-ear monitors is channelled through a range of equipment both on and off stage. Besides standard vocal microphones, additional microphones must be placed in front of guitar amplifiers and around drum kits. These microphone signals are sent to a monitor mixing board where they are adjusted to each performer's sound preference. The processed signal is then sent back to the musician's belt-pack amplifier via a hard-wired or wireless transmitter, and then to the in-ear monitor.

Advantages associated with the use of in-ear monitors include:

- The hi-fidelity micro-transducers in custom-moulded earplugs allow musicians to control the mix and overall loudness of their own voice and instrument. They can also balance these loudness levels in relation to the rest of the band (ie other musicians) more effectively. This often results in improved sound quality over conventional stage monitors.
- Varying room acoustics in different venues have a great deal of influence on the sound coming from a stage monitor. In-ear monitors, with high isolation from ambient sound, provide a consistent sound because the acoustic environment (the ear canal) is not greatly affected by variations in room acoustics. This gives consistent sound quality from venue to venue.
- With stage monitors, the musician is forced to either stand directly in front of a loudspeaker or line up consecutive loudspeakers across the stage. Using wireless FM transmitters with in-ear monitors, the musician is free to go anywhere on stage without sacrificing sound quality.
- Because of feedback, stage monitors cannot always be turned up loud enough to be heard, and so vocalists put undue strain on their vocal cords to hear themselves. Elimination of stage monitors and feedback also eliminates vocal fatigue.
- A reduction in the overall noise levels on stage.

Manufacturing techniques, transducer types, transducer combination, degree of isolation from ambient sound and construction materials vary among in-ear monitor manufacturers. There is currently no standard test for governing their performance in terms of the amount of noise they attenuate and generate. Although miniature in size compared to conventional stage monitors, they are still capable of producing very high sound pressure levels, up to 120 dB(A) at the ear. Peak limiters or compressors can be used to prevent accidental exposure to very high noise levels from feedback or other equipment malfunctions. However the real danger from these devices is everyday use at levels that exceed the exposure action values. In-ear monitors are amplified through a variety of monitor boards, transmitters and belt-packs from different manufacturers, and it is very difficult to predict the actual output based on manufacturers' specifications alone. It is essential that musicians are educated in the safe use of in-ear monitors. They should be made aware of the need to protect their hearing by using available methods to control the monitor's output levels, such as volume adjustment and limiter circuits.

The manufacturers of some in-ear monitors claim their products provide noise attenuation up to 25 dB (with no input). However there are currently no standard tests for governing the performance of custom-moulded electronic earplugs. In the absence of a standard test, any noise reduction claims made by manufacturers and suppliers must be substantiated with evidence, for example BS EN 352-2 attenuation data. Contact was made with a company who supply custom-moulded communication earplugs that are fitted with a filter to musicians. These earplugs were originally developed for covert police operations. The company provided test data for this product, which had been obtained using the test methods specified in BS EN 352-2, EN 24869-1 and pr EN 352-6: 1998 (now BS EN 352-6: 2002).

4 MUSICIANS' ATTITUDES TO HEARING PROTECTORS – A LITERATURE REVIEW

There is evidence to suggest that prolonged exposure to music can result in permanent hearing damage. The use of hearing protection can reduce these damaging effects. Although most rock musicians use hearing protection, at least while rehearsing (Laitinen, 2005), the use among classical musicians is uncommon for a variety of reasons:

- Musical practice and performance require the professional musician to accurately match frequencies over a broad range in order to play proficiently. Some musicians fear that the use of hearing protection may lead to unacceptable pitch or loudness discrimination (Henahan, 1985; Eaton et al, 2002; Peters et al, 2005; Bloom, 2006; Curk et al, 2006).
- The occlusion effect, which is an enhancement of low frequency bone-conducted sound due to plugging the ear canal. It is a particular problem for vocalists and musicians whose instruments are in contact with their head/face, eg brass and woodwind players. The occlusion effect makes it very difficult for musicians to monitor their own playing and that of other musicians in the ensemble (Teie, 1998; Chasin, 1992; Eaton et al, 2002).

Two studies have been carried out to investigate musicians' use of hearing protectors. Laitinen (2005) used questionnaires to study the factors affecting the use of hearing protectors among 196 classical musicians playing with five major orchestras in Helsinki. String, flute, woodwind, brass and percussion players were represented in the sample, and almost half had been playing in a professional orchestra for over 20 years. Curk et al (2006) obtained completed surveys for 283 amateur and professional percussionists (representing all styles of music and musical settings) using questionnaires or personal interviews. The majority of musicians reported playing for 11 to 20 years.

In both groups of musicians job satisfaction was high, with over half agreeing with the statement that their work was "inspiring and meaningful". There was a high degree of awareness (up to 90%) that exposure to loud music could result in permanent hearing damage for which there was no cure. In both studies hearing protectors were used more commonly during rehearsals and performances, but were rarely used during individual rehearsals. The main factors affecting the use of hearing protectors identified from these two studies are summarised in the following sections.

4.1 REASONS FOR WEARING HEARING PROTECTORS

Hearing protectors were used more frequently by musicians suffering from hearing damage symptoms (such as existing hearing loss and tinnitus) than those without symptoms. There was awareness that permanent music-induced hearing loss could have some serious consequences, including not understanding speech, not being able to hear subtle sounds when performing, and not hearing faint or high-pitched sounds.

Among those musicians wearing hearing protection, there was the belief that hearing protectors could save hearing, prevent tinnitus, make loud sounds more comfortable, reduce loudness without causing distortion, prevent fatigue, decrease stress, irritation and fatigue due to pre-existing hearing loss and tinnitus, and protect the ears from pain.

The number of musicians wearing hearing protectors increased following appropriate training and education (including the provision of a free pair of custom-moulded musicians' earplugs). Following this training, musicians reported wearing hearing protectors more often because they were more aware of the dangers of loud music, more aware of musician-quality earplugs, because they received a free pair of musician-quality earplugs, or learned that they were at risk of music-induced hearing loss.

4.2 REASONS FOR NOT WEARING HEARING PROTECTORS

Musicians gave the following reasons for not wearing hearing protection:

- Hinders their own performance by affecting the sound quality
- Difficult to hear others play
- The sensation caused by wearing hearing protectors is unpleasant
- They are too difficult to insert and it's too much hassle
- They interfere with communication during rehearsals
- An existing hearing loss makes their use difficult
- A belief that they are not needed
- The cost
- The appearance
- Not wanting to be seen as having "weak" hearing in a business that is all about subtlety and nuance

The most commonly reported effects were related to the sound quality of the musician's own music and that of their colleagues, and the perception that wearing hearing protectors was too much "hassle" because of difficulties with fit and communication.

4.3 TYPES OF HEARING PROTECTORS BEING USED

The musicians reported currently using the following types of hearing protection:

- Custom-moulded musician-quality earplugs
- Premoulded musician-quality earplugs
- Disposable foam/wax-moulded earplugs
- Reusable (premoulded) flange earplugs
- Headsets
- Cotton, tissues and hands

The most popular types were custom-moulded and premoulded musicians' earplugs and conventional foam/flange earplugs. Laitinen et al (2003) assessed the performance of four different types of musicians' earplugs including custom-moulded and premoulded devices. The

attenuation data supplied with the hearing protectors was used with typical A-weighted and C-weighted noise levels generated by the musicians to estimate the effective A-weighted sound pressure level at the ear. The HML check method described in BS EN 458: 2004 was used. The results showed that three of the four earplugs were capable of reducing the A-weighted noise level at the ear to below 85 dB.

Disposable earplugs were popular with some of the musicians who found custom-moulded earplugs difficult and slow to use. They chose disposable earplugs when they needed protection quickly because they perceived that this type of hearing protection is quicker and easier to fit. However it takes time to properly insert disposable earplugs, and if they are not fitted correctly they will not make a good seal with the ear canal, which will reduce the attenuation of the earplug. It is therefore possible that those musicians are under-protected when using disposable earplugs.

Although flat frequency response hearing protectors have been designed for musicians, it is not easy to start using them. The musician needs to get used to the feel of the earplugs and also to how they change the sounds that the musician hears. The manufacturers recommend that the musician initially wear the earplugs at home, then for individual practice, building up to group rehearsals and performances. It can take two to three months for musicians to get used to new earplugs, although this can vary between individuals.

One of the most surprising (and disturbing) results to come out of the two studies carried out to investigate musicians' use of hearing protectors, was that 24 professional musicians out of a sample of 196 reported using cotton, tissues and hands as a method of reducing their noise exposure. It suggests a real and urgent need for an effective education programme.

4.4 GENERAL CONCLUSIONS ABOUT HEARING PROTECTOR USAGE

Musicians are sensitive to many hearing symptoms and seem to be keener to start using hearing protectors once the symptoms appear. Although musicians are worried about their hearing, the use of hearing protectors is low and especially neglected in individual practice. Laitinen (2005) and Curk et al (2006) both found that the use of hearing protectors is related to motivation. To increase the number of musicians wearing hearing protection, a good education programme is essential which should include information on the following:

- The warning signs of hearing loss, including tinnitus and temporary threshold shift
- Dangers of exposure to loud sound
- Sound pressure levels experienced by musicians
- Types of hearing protection available and the benefits of each type

It is important to note that the provision of training and information would only be effective if delivered as part of an on-going process, with important messages reinforced on a regular basis.

5 MUSICIANS' ATTITUDES TO HEARING PROTECTION – TELEPHONE INTERVIEWS

A qualitative study was carried out to gain a range of opinions and in-depth information on musicians' attitudes towards hearing protection. Semi-structured telephone interviews were conducted with nineteen musicians between June and October 2007.

5.1 METHODOLOGY

Semi-structured interviews allow information on pre-defined topics to be collected from interviewees. The method is flexible, and it gives the interviewer the opportunity to use follow-up questions in order to elicit more detailed information where appropriate. Semi-structured interviews allow the main topics to be covered while enabling the interviewee to answer in a comprehensive manner, so eliciting the maximum amount of information from each question. A final question, for example "*Do you have any further comments to add?*" will both encourage and allow the interviewee to raise any points that may have been missed during the interview, to elaborate further on any points that they think may be pertinent to the study, and to emphasise points that they feel most strongly about. Unlike questionnaires with standardised questions and closed-ended answers, semi-structured interviews only include general questions. This leaves the interviewer free to rephrase them as appropriate and to add further questions based on the interviewee's answers and the conversation flow. Semi-structured interviews also allow for unexpected information to surface during the interview.

5.2 SAMPLING STRATEGY

Contact details of organisations willing to help with this qualitative study were obtained, mainly from HSE specialists; these included the Musicians Union, the Ministry of Defence, the British Broadcasting Corporation (BBC), and the Association of British Orchestras. These organisations then provided details of professional musicians willing to take part in the telephone interviews. In addition, several freelance musicians also agreed to take part in this study. Participation in the study was completely voluntary, and the musicians were informed at the start of the interviews that the information obtained would be anonymised for inclusion in the final report.

5.3 TOPICS COVERED DURING THE TELEPHONE INTERVIEWS

The semi-structured telephone interviews were based on the topics described in Appendix D. The same interviewer carried out all the telephone interviews. This ensured that all the questions were interpreted in the same way so that any issues of ambiguity and/or common misunderstandings could be addressed.

5.4 ANALYSIS

Thematic analysis was used to analyse the data obtained from the telephone interviews. This technique is used to identify, analyse and report patterns (themes) within data (Braun et al, 2006). Analysis was carried out on transcriptions of all the telephone interviews, which were systematically analysed to identify as many potential themes/patterns as possible.

5.5 RESULTS

5.5.1 Musicians' details

Table 1 contains details of the nineteen professional musicians who took part in the telephone interviews.

Table 1: Musicians' details

Musician ID	Instrument	Range of current work experience	Work environment	Length of time as professional musician	Employed or self-employed
M1	String (cello)	Orchestra, teach, examiner	Orchestra pit	> 25 yrs	Employed
M2	String (viola)	Orchestra, teach during term time	Studio, concert halls	23 yrs	Employed
M3	Brass (trombone)	Orchestra, freelance	Studio, concert halls	25 yrs	Employed
M4	Percussion	Orchestra, freelance	Studio, concert halls	14 yrs	Employed
M5	Percussion	Orchestra, teach during term time, occasional freelance	Studio, concert halls, teaching room and sound proofed booths (acoustically adapted to industry standard)	25 yrs	Employed
M6	Woodwind (piccolo)	Orchestra, freelance	Mostly large studios	20 yrs	Employed
M7	String (cello)	Orchestra, teach, occasion freelance	Orchestra pit	30 yrs	Employed
M8	Woodwind (clarinet)	Orchestra	Orchestra pit	30 yrs	Employed
M9	Percussion (drums)	Freelance (corporate gigs, theatrical musicals)	Various	4 yrs	Self-employed
M10	Percussion (timpani)	Orchestra, occasional master class/session	Orchestra pit	40 yrs	Employed
M11	String (violin)	Orchestra	Orchestra pit	26 yrs	Employed
M12	Percussion (drums)	Freelance (pop, rock, soul, contemporary), session musician, functions, teach	Various	13 yrs	Self-employed
M13	Percussion	Teach, freelance (brass, orchestral, rock)	Various, school music rooms	7 yrs	Employed (teaching), self-employed
M14	Brass (tuba)	Orchestra, occasional freelance	Studio	10 yrs	Employed
M15	Brass (French horn)	Orchestra, teach, occasional freelance	Large concert hall, studio	36 yrs	Employed
M16	Woodwind (contrabassoon)	Orchestra, occasional freelance	Studio, concert halls	30 yrs	Employed
M17	String (viola)	Orchestra, occasional freelance, examiner	Large concert halls, studios	22 yrs	Employed
M18	Percussion	Military band, freelance	Parade, rehearsal studio	20 yrs	Employed
M19	Woodwind (piccolo, flute)	Military band, freelance, teach	Parade, rehearsal studio, recording studio, concert halls, practice rooms	15 yrs	Employed

The sample interviewed included fourteen classical musicians working with large orchestras, three freelance percussionists, and two musicians who played with a military band. Details of the range of the musicians' current work are shown in Figure 6.

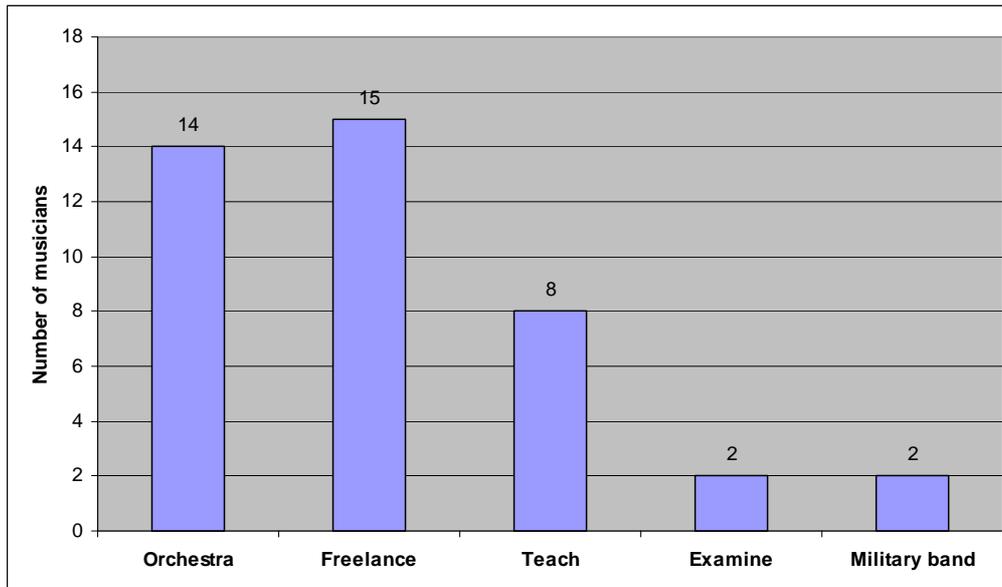


Figure 6: Musicians' current work experience

The majority of musicians (14) were employed full time with an orchestra, although many had contracts that allowed time for freelance work outside the orchestra. Fifteen of the musicians reported doing freelance work, either as their main source of income (3 were self-employed) or in addition to their main source of income (12). The type of freelance work included playing with other orchestras, big band jazz, corporate gigs, theatrical musicals, brass, rock, master classes and session work. Eight of the musicians taught music, either privately (7) or employed by the education authority (1), and two of the musicians were qualified music examiners.

The musicians played a range of instruments including cello, viola, trombone, percussion, piccolo, clarinet, timpani, violin, tuba, French horn, contrabassoon, and flute. Figure 7 shows the number of musicians playing in each instrument group, where the instruments were classified according to the following scheme:

- Woodwind: flute, oboe, clarinet, bassoon
- Brass: horns, trumpets, trombones, tuba
- Percussion: timpani, cymbals, snare drum, bass drum, xylophone, etc
- String: violin, viola, cello, double bass, harp

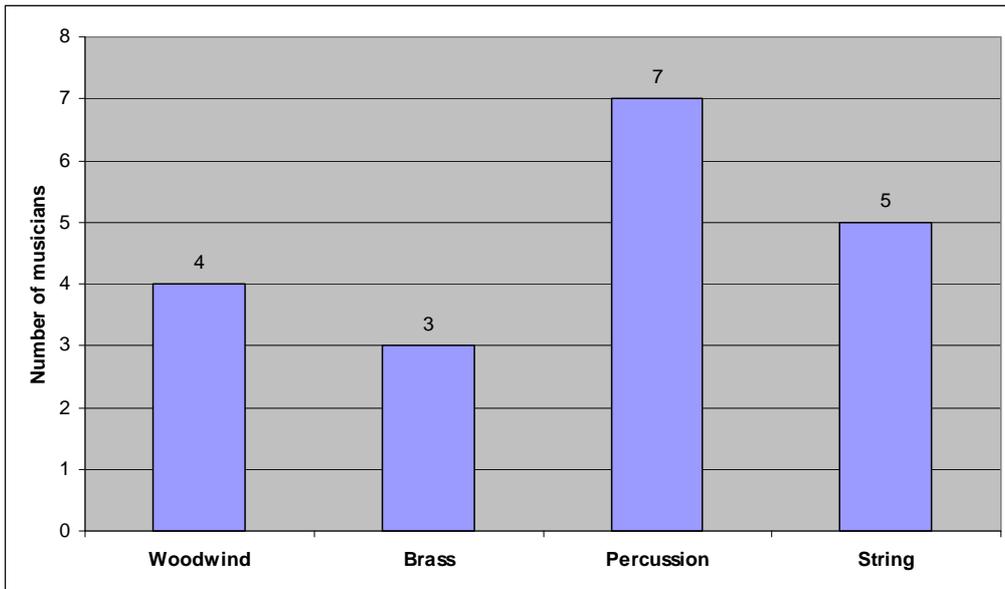


Figure 7: Instrument details

The musicians had been playing professionally for various lengths of time ranging from 4 years to 40 years (mean 22 years, standard deviation 10 years). They had experience of playing in a range of different venues as shown in Figure 8.

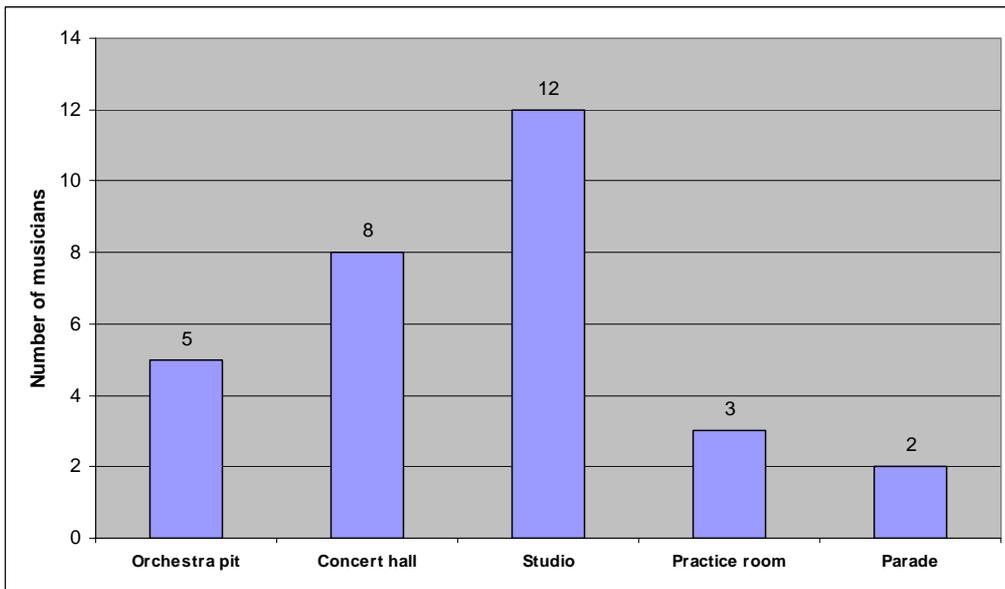


Figure 8: Work environment

5.5.2 Musicians' noise exposure

The musicians were asked to estimate their exposure times, ie the number of hours they were exposed to the noise generated by the music they play professionally, including rehearsal and performance times. Most of them found this quite difficult because the length of time they play depends on several factors including the type of work they carry out, the piece of music (eg an opera can be between 3 and 5.5 hours long), and on how much rehearsal time is needed. It was

difficult for the freelance musicians to estimate duration because their workload is generally unpredictable.

Estimates of the musicians' exposure times were between 14 and 42 hours per week (mean 28 hours, standard deviation 7 hours). The orchestral musicians contracted to large orchestras reported that an upper daily limit was placed on their playing time (rehearsal and performance). An upper limit of 6 hours per day was reported by nine of the musicians, five musicians reported an upper limit of 7 hours per day. Comments on these upper exposure times included:

“Management are not keen to implement this upper limit because it is seen as a benefit to the musicians”

“There is a limit of 6 hours per day but it isn't enforced”

Only three of the musicians made any reference to personal practice sessions:

“I practice at home 2 hours per day, 3 to 4 days per week in a small room with poor acoustics”

“I generally work up to 7 hours per day which includes rehearsal and performance time. I'm generally too tired to do additional practicing after working a 7 hour day.”

Over half of the musicians (11) who took part in this study were aware that noise assessments had or were being carried out by their employer. These assessments involved monitoring noise levels during rehearsals and performances, in various sections of the orchestra, and for different pieces of music. Five of the musicians had received no feedback; six had received the following feedback:

“Broad range of A-weighted levels, some over 100 dB, localised “hot spots” within the orchestra”

“Average levels below exposure action values”

“A-weighted sound level in studio is 85 dB”

“A-weighted noise level is 90 dB, localised “hot spots” in the orchestra”

“No feedback on daily personal noise exposure, but average A-weighted noise level is 87 dB, average C-weighted peak noise level is 133 dB”

“Exposed to occasional peaks but within the limits”

Eight of the musicians in this sample had not had their noise exposure assessed; this included all three self-employed musicians. Two of these musicians (both self-employed) had borrowed sound level meters to measure the levels of noise they were exposed to: one had measured 110 dB two feet from his drum kit. These musicians were both curious about how loud their music was, and they commented on the lack of information and support available for freelance musicians.

The musicians were asked to subjectively rate their current noise exposure: five judged their noise exposure as significant; twelve said they were regularly exposed to loud noise but that the very high levels were generally not sustained for long periods; and two described their noise exposure as varied. The musicians identified many sources that contributed to their noise exposure including:

- The noise generated by their own instrument (11)
- The noise generated by other musicians' instruments (17)
- The type of music being played (4)
- The seating position within the orchestra (8)
- The type and size of the venue (7)
- Crowd noise (1)
- Playing on parade (1)

A sample of the musicians' comments on these noise sources is given below:

"My own instrument is a more significant source of noise exposure when sat near quieter instruments"

"Most noise exposure is due to my own instrument (timpani) unless I'm sitting near the brass section"

"The orchestra plays a lot of contemporary music – the levels are usually quite high and painful"

"The orchestra mostly plays 19th century romantic style music which is generally quieter than modern operas"

"Noise exposure depends on the repertoire – pieces of music are put together to satisfy programming needs rather than limit noise exposure"

"As a piccolo player, the worst exposure occurs when practicing in small rooms which are poor acoustically"

"Exposure to high noise levels is exacerbated by playing in a pit rather than on stage"

Almost half the musicians (8) thought that their seating position within the orchestra had an impact on the level of noise they were exposed to because of the instruments played by other musicians sitting close by. Instruments identified as contributing to the musicians' noise exposure included percussion (9), woodwind (10) and brass (12). Ten of the musicians always sat in the same position within the orchestra, while the seating position of six of the musicians varied depending on either the repertoire, the sound the musical director was trying to achieve, or because it was policy to regularly rotate musicians within the orchestra.

5.5.3 Musicians' hearing

The majority of musicians (16) had had their hearing assessed, either through their employer (14) or privately (2). Audiometry was most commonly carried out at the start of employment (5) or when requested. Four of the musicians reported having regular hearing checks, either annually (3) or every 5 years (1). Only one of the musicians said they would like their employer to regularly monitor their hearing.

Several concerns were raised about health surveillance including the quality of tests offered, the availability of tests when occupational health services are outsourced, confidentiality issues

where the employer provides health surveillance, and whether health surveillance is compulsory under the Control of Noise at Work Regulations 2005, which came into force in the music and entertainment industry in April 2008.

No diagnosed hearing loss was reported. However hearing checks had shown slightly reduced hearing sensitivity at high frequencies for five of the musicians, which was attributed to age (2) or possibly due to being a professional musician (3). Figure 9 shows details of other hearing problems that were reported by the musicians interviewed for this study.

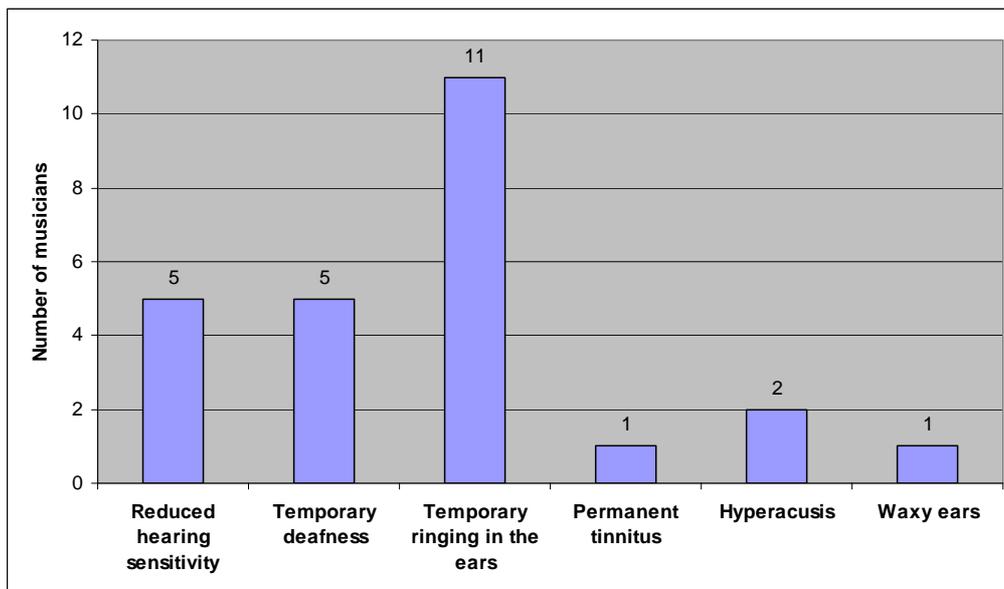


Figure 9: Musicians’ reported hearing problems

Three of the musicians felt that the ear might have a natural defence mechanism against the loud sounds generated by their own music:

“I have very waxy ears and have adapted my playing accordingly – I wonder whether this provides a natural defence against damage because my ears never seem to hurt when I generate loud peaks”

“I think the ear has a natural defence, within the middle ear, against the sound you generate yourself”

The experience of these musicians may support evidence of the stapedial reflex, which is thought to provide protection against intermittent loud noises due to the contraction of a muscle in the middle ear (Chasin, 1999). More details of this response are contained in Appendix B.

5.5.4 Hearing protection

Hearing protection was provided free of charge by the employers of fourteen of the musicians interviewed; three of the musicians purchased their own hearing protection either because they were self-employed (2) or they didn’t like the type of protectors supplied by their employer (1). The use of hearing protection was optional for eighteen of the musicians. Only one musician played with a large orchestra that had made the use of hearing protectors compulsory for those musicians whose A-weighted noise exposure exceeded 85 dB. The musician reported that this policy is not enforced.

5.5.4.1 Use of hearing protection

Six of the musicians interviewed during this study did not use hearing protection (3 percussionists and 3 brass players). They gave the following reasons for not using hearing protection: it is impossible to play properly when wearing hearing protectors (5); hearing protectors are uncomfortable (2); and noise exposure is not high enough to cause hearing damage and therefore hearing protection is not necessary (3). Some of the comments made by these musicians are given below:

“You get no feedback with hearing protectors and because you hear lower noise levels you tend to play louder to compensate, which increases overall noise levels”

“When playing a brass instrument, the cavities in your head are part of the sound because air within them vibrates. With earplugs, I can hear the vibrations within my head rather than the sound coming out of the bell so I don’t get an accurate representation of the sound I’m making. This makes it difficult to adjust my playing to fit in with other players.”

“I don’t think there’s a (noise) problem – everyone is just jumping on the bandwagon. My noise exposure was assessed over a six month period and the results were completely inconclusive.”

Thirteen of the musicians interviewed used hearing protection; one would not play without it and twelve said that they wear hearing protection when they feel they need it, for example when the music becomes uncomfortably loud (2), when sitting near to the brass or percussion sections (3), teaching (1), and on parade (1). Nine of these musicians (6 woodwind and 3 string players) would not use hearing protection when playing a solo or an exposed piece of music, ie music that makes a significant contribution to the overall sound generated by the orchestra (eg a piece played just by the string section). Some of the comments made by the musicians on the use of hearing protection for solo playing included:

“I wouldn’t wear any hearing protection when playing solo because my playing has to be absolutely precise in these conditions and hearing protectors dull my hearing sensitivity and awareness of how others are playing”

“I don’t feel I can play to the same high standard when wearing my earplugs”

“I can’t hear my own sound properly with hearing protectors and this causes me to doubt my ability”

“I worry about playing in tune when wearing plugs and I will not wear them when playing a solo”

5.5.4.2 Types of hearing protectors being used

The type of hearing protection that were being worn or had been worn included:

- Earmuffs (2)
- Sound restoration earmuffs (1)
- User formable (foam) earplugs (10)
- Premoulded (flange and domed) earplugs (5)

- Custom-moulded flat response earplugs (15)
- Non-custom moulded flat response earplugs (2)
- In-ear monitors (2)

The musicians interviewed rarely used earmuffs. One musician playing an exceptionally loud piece of music in an orchestra pit wore heavy-duty muffs. It was difficult to play well wearing these muffs, but the noise levels were sufficiently high for this not to be a concern for the musician. It is unlikely that musicians playing on a stage would wear heavy-duty earmuffs because of the visual impact on the audience. Sound restoration muffs were also rarely used; one musician had tried them and commented “*the variable attenuation works well allowing precision playing during quieter musical pieces*”.

The majority of musicians (15) had worn or were using standard earplugs. The main disadvantage associated with standard earplugs was that they distort the sound of the musician’s own music (6), which makes it difficult for them to play properly. However the musicians also identified several advantages associated with using standard earplugs: easy to fit during a performance (5) especially those which are attached to a cord; variable protection achieved when needed by either loosely fitting the plug or pushing it further into the ear canal (4); and easily (readily) available (11), for example usually located in dispensers at the entrance of the studio:

“Foam plugs are very easy to fit during a performance. I wear them loosely fitted when the music is quiet, and push them firmly in when the noise level increases”

“Although I have custom-moulded plugs I often forget to bring them, it is good having easy access to disposable plugs at the studio”

[Note: Loosely fitting earplugs in the ear is NOT an effective way of protecting hearing, and it is possible that earplugs will not provide any protection when fitted this way. The attenuation data supplied with earplugs assumes that they are fitted correctly according to the manufacturer’s instructions. It would therefore be impossible to estimate the amount of protection an earplug gives the user when it is not fitted correctly.]

The majority of musicians (15) had been fitted with custom-moulded musicians’ earplugs. One of the musicians commented that “*the performance of these plugs is irrelevant – when the music is loud it doesn’t matter if you can’t hear all the frequencies, you can’t even hear yourself playing*”. Seven of the musicians used custom-moulded earplugs regularly, however none wore them all of the time either during rehearsals or performances. Five of the musicians reported that they found it difficult to fit custom-moulded earplugs:

“It is hard to fit my custom-moulded earplugs quickly in the middle of a performance (it can take up to 30 s per ear) especially when holding an instrument”

“I often have less than 1 s to remove my hearing protectors before playing a solo piece”

Five of the musicians commented that their custom-moulded earplugs were fitted with filters that were unsuitable for the level of noise they were exposed to; they either provided too much or too little protection. Three musicians reported problems that were attributed to poor moulds. These musicians had abandoned custom-moulded earplugs because they either “*blocked out all sound completely*”, “*didn’t fit properly and let too much noise in*”, or “*were inserted so deeply they made me cough*”. In two cases, the manufacturers acknowledged that the problem was

probably due to poor moulds, however the musicians had declined the offer of having the moulds redone.

The musicians gave differing opinions regarding the comfort of custom-moulded earplugs. Two found them uncomfortable, while two found them comfortable:

“Custom plugs can sometimes cause soreness in my ears because of the close fit”

“Custom-moulded earplugs fit better (than foam or flange earplugs) and are therefore more comfortable”

Advantages associated with the use of custom-moulded earplugs were identified. Six of the musicians reported custom-moulded earplugs preserved a more natural sound quality compared to standard earplugs. Although this made them “great for listening to music” none of these musicians said that they would wear them for solo or exposed performances:

“Custom-moulded earplugs are excellent when the orchestra is playing a really loud piece of music – the music from my colleagues is not distorted, just quieter”

“Custom-moulded earplugs are much better than standard plugs but they still alter my perception of the music I generate”

“The sound quality is much better with custom-mould earplugs than standard foam plugs”

Another advantage associated with the use of custom-moulded earplugs was that they are unobtrusive. Two of the musicians felt using hearing protectors that protruded from the ear would be visually distracting or unacceptable to the audience:

“The earplug is fitted with a stalk that sticks out of the ear by about one-inch, which looks a bit strange”

Two of the freelance, self-employed percussionists used premoulded musicians’ earplugs. The main advantage of these earplugs was that they preserve and even improve the sound quality at a relatively low cost. These musicians also used in-ear monitors, which they thought, “were great”. In-ear monitors provide a method for controlling the level of incoming sound when used with a personal mixing desk, and the earpiece provides some isolation. One of the musicians expressed concern that at large gigs musicians have to take responsibility for limiting their own noise exposure, for example by using a personal submixer or volume limiter because:

“Soundmen often plug in-ear monitors straight into the main output, which is usually set at a high level to feed the amplifiers”

“There is often no overall control (of noise levels) at large gigs”

5.5.4.3 Information and training

The musicians had been given the following information and training:

- How to correctly fit their hearing protectors (8)
- How to clean and maintain their hearing protectors (7)

“I’ve found my plugs need to be regularly replaced because sweat, wax and heavy-use damage the material which results in a poor seal”

- How to get used to wearing and playing in custom-moulded earplugs (4)
“The supplier advised me that it was essential to get used to playing in (custom-moulded) earplugs – you’ve got to accept the attenuated music as the normal sound”
- General training on noise including the possible risk of hearing damage and the introduction of new noise regulations (4)
“We have very good, compulsory training on noise – however it is generally only the large orchestras who have funding for this”
“My employer is engaged in a lot of training at the moment, the orchestra has a hearing conservation programme and we’ve been directed to the HSE website for information on the new noise regulations”

The only information on fit and maintenance available to four of the musicians (two were self-employed) was the information contained in the manufacturer’s instructions supplied with the protectors. Only one of the musicians using custom-moulded earplugs had been advised that the moulds might need redoing because of material damage and possible changes to the size and shape of the ear canal with time that might affect the fit:

“I was advised that the plugs would be good for 2 to 5 years, after which I may need to get the moulds redone”

5.5.4.4 Advantages of using hearing protection

The musicians identified the following as advantages associated with the use of hearing protection:

- Protect hearing (8)
- Reduce or block out loud music generated by other musicians (7)
- Reduce the incidence of pain in the ears, temporary deafness, and ringing in the ears (4)
- Improve sound quality (3)

Two of the freelance drummers reported that using hearing protectors improved sound quality:

“The earplugs take out high frequencies so that the music sounds less tinny and therefore warmer”

A third percussionist made the following comment:

“My plugs take out the harshness from the cymbals positioned behind me – this helps enormously”

5.5.4.5 Disadvantages of using hearing protection

The musicians identified the following as disadvantages associated with the use of hearing protection:

- Compromises performance (13)
- Difficult to fit during a performance (4)
- Difficult to communicate with the conductor (2)
- Uncomfortable (3)
- Visually distracting for the audience (2)
- Unable to fully enjoy the music generated by your own instrument (4)

The majority of musicians (13) said that the use of hearing protection compromised their playing. The most common reason given for this was that hearing protectors prevent the musicians from hearing properly the sound generated by their own instrument (6). Consequently it is difficult for them to make fine adjustments to their playing (6), to control how loud or soft they are playing (3), and to confidently play in tune with other players (4). Only one of the musicians reported that with practice they had gained some confidence in playing with earplugs. However this musician was still unwilling to use hearing protection when performing a solo piece. Seven musicians felt that they were unable to play at the highest possible standard when using hearing protection:

“I can adjust my playing when wearing earplugs by knowing how hard I should blow, but I lose the fine adjustment. No one has ever complained about my performance when using plugs but I don’t feel it sounds as good.”

“I worry I will lose the ability to play at the highest standard if I continue to play with hearing protection for a long time”

Five of the musicians interviewed felt that it was very stressful and demoralising not being able to play at the highest possible standard when wearing hearing protectors:

“I find it very stressful wearing hearing protectors – I make more mistakes and I think using them compromises my ability to play at the highest standard”

“Using hearing protectors compromises my performance and I worry the resultant sound is not good enough – this is demoralising and depressing for a professional musician”

Four of the musicians (2 woodwind and 2 brass players) identified the occlusion effect as a disadvantage associated with the use of hearing protection. These musicians generate music by blowing into their instrument. Wearing hearing protectors changes the musicians’ perception of the sound they make and of other sounds generated within their bodies. The following comments were made:

“I sound like a beginner to myself when I’m using earplugs”

“I tried earplugs but was horribly conscious of noises rattling inside my head”

“I can hear buzzing in my head, however wearing just one earplug improves this”

5.5.4.6 Factors affecting the use and selection of hearing protection

The following factors were identified as having an impact on a musician's decision to wear and select a particular type of hearing protector:

- Comfort (7)

“Uncomfortable hearing protectors will get in the way of my performance”

- Ease of use during a performance (8)

“I need to be able to easily fit my plugs in and out during a performance”

Although ease of use was an important factor, two of the musicians expressed the following concerns:

“Fitting the plugs in and out during noisy and quiet parts of a performance spoils the continuity of the music”

“It's okay to put earplugs in and out during a concert when musicians are in an orchestra pit. I think this would look awful for musicians sitting on a concert platform.”

- Variable attenuation (2)

“There is a lot of variation within the music that means hearing protectors can be fitted and removed several times during a performance. Protectors with variable attenuation are needed.”

- Quality of attenuated music (9)

“It is essential that the quality of the music heard through the hearing protector is maintained”

- Cost (3). The three self-employed musicians reported that although it should not be an issue, the cost of some types of musicians' hearing protection was too expensive. The cost of hearing protection was not considered important by nine of the musicians; their employers provided it free of charge.

“Cost shouldn't be an issue, but I've made some expensive mistakes. I now use an audio hire company that allows me to trial new products before buying them.”

The following factors were judged to be the most important by the musicians interviewed:

- Easy to use and quick to fit (8)
- Preserve sound quality and allow effective playing (7)
- Reduce (painfully) loud music (3)
- Unobtrusive (2)
- Provide variable attenuation (2)

- Comfortable (1)

The following factor was judged to be the least important by the musicians interviewed:

- Cost (6)

5.5.5 Other control methods

The musicians identified a wide range of control methods that have been used to control their noise exposure, including:

- Regularly rotating playing positions within the orchestra (5) so that players are not always sitting close to noisy groups of instruments such as brass and percussion.

“We are rotated on a weekly basis to practice playing in different positions within the orchestra – this is good musically and it can reduce noise exposure”

- Acoustic screens (8) have been used, however they can give a hard edge to the music, they don't work for brass players because the reflected sound changes what the player hears, string players perceive no effect at all, they can present a tripping hazard especially where space is limited, and they can be distracting for the audience.

“Screens don't work because of the problems associated with reflected sound”

- Increasing the separation between individual musicians, and between different sections of musicians, was identified as an effective control method by almost half of the musicians interviewed (7).

“Increasing separation – even by a few inches – makes a noticeable difference”

- Using podiums, risers and platforms was described by four of the musicians as a method of reducing their exposure to loud noise from other players, particularly brass players. However careful stage design is needed.

“Placing the string section on podiums increased our noise exposure from the brass section”

- Programme planning (1)

“There is some scope for putting together a repertoire that limits noise exposure but the programme also needs to be exciting to attract audiences”

- Playing at lower noise levels during rehearsals can limit noise exposure (1)

“We give the conductor the balance it's going to be during the performance once, then turn the volume down for the rest of the rehearsal”

- Use of larger, acoustically treated practice rooms and studios (2)

“We are currently playing in a studio that is not large enough to accommodate the full orchestra – there is no room for spacing and noise levels are too loud”

- Freelance percussionists (2) recommended use of a personal mixing desk and in-ear monitors.

“The mixing desk gives full control over the signal level input to the in-ear monitor and the earpiece cuts out the excessive noise generated by other musicians on stage”

- One of the freelance musicians had experience of a sound limiting system at a large venue. It consisted of a light positioned above the stage that turned red if the noise levels exceeded a particular level. If the light remained illuminated for more than 3 s the power to all the equipment on stage was cut.

“Cutting the power suddenly isn’t good for equipment so these systems are often, and easily, overridden”

- Four of the musicians reported blocking their ears with either their hands or fingers during particularly loud periods of music.

“I make a note of when these (unbearably loud percussion) moments are coming and put my hands over my ears”

- Five of the musicians commented that their noise exposure was higher when playing in the confined space of an orchestra pit compared to playing on an open stage.

“Playing on a stage or platform is far better than playing in an orchestra pit in terms of sound quality and noise exposure”

Two of the musicians interviewed play in a military band, which includes regularly playing with the marching band. These musicians recognised the difficulties of using many of the control methods available to other types of musicians, other than hearing protectors.

5.5.6 Other comments

Seven of the musicians raised issues about the impact of implementing the requirements of the Control of Noise at Work Regulations 2005 in the music and entertainment industry. There was concern about the following:

- The career prospects for musicians seen to be wearing hearing protection or reporting hearing loss (1)
- The impact on the business if musical programmes cannot include the loud (and usually exciting) pieces of music, if stages are cluttered with control measures such as screens, and if the audience observe musicians fitting hearing protectors during performances (3)
- The prospect of controlling noise exposure by limiting the amount of playing time, which will have an impact on salary (1)
- The use of hearing protectors may become compulsory (1)
- Orchestra managers may issue hearing protectors as an easy way of complying with the regulations (1)

“I worry that issuing hearing protectors is an easy option for management – it puts the responsibility on to players who have to use hearing protection and struggle with trying to cope with the end result, when stage design and increased separation between instruments are likely to be more effective at reducing noise exposure”

Three of the musicians felt that it was important to raise awareness among young musicians of the risk to hearing from exposure to loud music:

“I am concerned about the hearing of young musicians who spend many hours practising on their own – an education programme is essential”

“We need to raise awareness among young musicians of the possibility of hearing damage – it would help if wearing hearing protectors was considered cool or if famous musicians endorsed their use”

Two of the freelance percussionists felt that more practical information should be available for drummers, especially regarding in-ear monitors (eg what they can do, cost, availability, limitations). The experience that these musicians had of in-ear monitors was largely self-taught, although one had studied the topic briefly at college.

It is possible that the use of hearing protection might be influenced by the type of instrument played, on the style of music played, and on the musician’s position within the orchestra:

- The musicians were more willing to wear hearing protectors when playing contemporary music, which contains a lot of percussion, compared to older romantic pieces of music (3) and when playing with a marching band (1) rather than in a concert because of the style of the music
- Some groups of musicians are always likely to be resistant to wearing hearing protectors (1)

“All principals, woodwind players who want to be as naked as possible when communicating their music with the audience, and most string players who feel a lot of vibration through the strings and don’t want to lose any connections between what they feel and hear”

- Three of the musicians reported that using hearing protectors was essential when sitting near to particular sections of the orchestra, for example a large brass section and percussion

“I occasionally wear plugs when playing – I wear them mostly when I’m positioned close to the horns”

5.6 DISCUSSION OF TELEPHONE INTERVIEW DATA

5.6.1 Sample details

Nineteen musicians were interviewed to gain an understanding of their attitude towards using hearing protection, and on the performance and usability of available hearing protectors. Although the sample was small it represented well the different types of instruments played, how long the musicians had played professionally, and the range of work experiences. The majority interviewed were classical musicians playing in large orchestras. However, the views of three freelance percussionists and two military band players provided some insight into the experiences of other types of musicians, playing different styles of music and in different venues.

5.6.2 Noise exposure

Most of the musicians found it difficult to estimate typical noise exposure times because of the range of work that they carry out (eg contract work, teaching, freelance), the type of music being played, and variable rehearsal times which depend on the difficulty of the piece of music being played. It was particularly difficult for the freelance percussionists because of the unpredictable nature of their work. Consistent with reports in the literature, very few of the musicians included personal practice sessions in their estimates of exposure durations. However it is likely that musicians playing full time with an orchestra would have neither the time nor the energy for additional practicing after work. The musicians also identified a wide range of factors that affect the level of the noise that they are exposed to, including proximity to loud sections of the orchestra, the type of music, and the type of venue. The results of the interviews reported here show how difficult it can be to estimate the level and the duration of the noise musicians are exposed to, and therefore how difficult it is to estimate their daily personal noise exposures in order to assess the risk of hearing damage.

5.6.3 Noise assessments

The information obtained during the interviews suggests that noise exposure assessments are generally being carried out, at least for employed musicians. However the musicians interviewed either received no feedback following the assessment, or they reported information that indicates poor assessments or a lack of understanding of the purpose of noise assessments; the musicians reported noise levels rather than noise exposures, and several musicians expressed concern about the validity of the measurements made. It is possible that more information will be available to the musicians, for example on how their noise exposure will be managed, under the requirements of the Control of Noise at Work Regulations 2005 which came into force in April 2008.

5.6.4 Hearing problems

The majority of musicians perceived that they were regularly exposed to loud noise, with occasional exposure to short bursts of very high noise depending on the music being played and their proximity to loud sections, eg brass and percussion. Most of the musicians had had their hearing assessed, although generally at the start of their employment and not as part of a health surveillance programme. None of the musicians reported diagnosed hearing loss. However they reported incidences of slightly reduced hearing sensitivity (possibly due to age or noise exposure), temporary deafness, temporary ringing in the ears, and hyperacusis, which they thought were related to exposure to music. The results obtained from this sample of musicians are consistent with those reported in the literature, ie low incidence of diagnosed hearing loss and higher incidence of hearing disorders. Information should be collected on hearing disorders among musicians since it might indicate hearing damage to other parts of the auditory system, even when there is no evidence of damage to the cochlea.

5.6.5 Hearing protectors

The purpose of the study reported here was to identify the types of hearing protection that musicians are currently using. Consistent with other published papers, a wide range are available although the majority of the musicians reported using standard foam or flanged earplugs and/or custom-moulded musicians' earplugs. Both types were generally provided free of charge to all the employed musicians. By comparison the freelance musicians interviewed either did not use hearing protection or they purchased it themselves, often based on limited information and with limited money to spend. A comparison of the most commonly used hearing protectors based on the musicians' experiences showed that although the sound quality

was better with custom-moulded musicians' earplugs, standard foam and flange earplugs were much easier to fit.

The majority of the musicians interviewed used hearing protection, but only when they felt it was needed. More importantly, most of these musicians said that they would never use any hearing protection when their playing made a significant contribution to the overall sound generated by the orchestra, eg a solo piece. The main problem was that orchestral musicians in particular do not believe they can play properly when wearing hearing protection; they believe all protectors alter the musician's perception of the sound that they make. This in turn affects the musician's ability, and probably their confidence, to play at the highest standard and with other players in the orchestra. By comparison the freelance percussionists reported that using hearing protection generally improved sound quality, and so there was much less resistance to wearing it compared to the orchestral musicians. However it is important to note that only three freelance percussionists were interviewed during this study and their views may not be typical. Other factors that affected a musician's choice to wear, or not to wear, particular types of hearing protector included whether they were quick and easy to fit during a performance, whether they were comfortable, and whether or not they were unobtrusive. Cost was not considered an important factor by most of the musicians interviewed during this study, however this was probably due to the fact they were employed by large orchestras who covered the cost of hearing protectors.

The majority of the musicians had received training on how to fit and maintain their hearing protectors, although the self-employed musicians generally relied on the information provided with the hearing protectors. Many of the musicians using standard earplugs commented that they were easy to fit, which made standard earplugs a popular choice. It is recognised that earplugs are often difficult to fit properly, even with training. Many of the musicians reported that loosely fitted earplugs gave sufficient protection (ie they took the edge off the very high noise levels), with the option of additional protection achieved by pushing the earplugs further into the ear when needed. It is important to highlight two points: loosely fitted earplugs might not provide any protection; and the performance of hearing protectors is assessed using the standard attenuation data supplied by the manufacturer, which assumes that the devices are fitted properly. It will therefore be difficult to assess the performance of standard earplugs that worn in a way to provide variable protection.

Although some musicians liked custom-moulded earplugs because of better sound quality and the fact that they were unobtrusive, the results from the musicians' interviews suggest that there are issues about ear-mould quality and training that need to be addressed. Several musicians had abandoned using custom-moulded earplugs because poor moulds meant that they were either uncomfortable to wear or they blocked out too much sound. Similarly some musicians had stopped using custom-moulded earplugs because they were fitted with filters that provided either too much or too little protection. Earplug manufacturers need to ensure that the quality of ear-moulds is of the highest possible standard, and that musicians are provided with earplugs fitted with appropriate filters.

Only a small minority of the musicians had received training on how to get used to wearing and playing with custom-moulded earplugs, and many found them difficult to fit, especially during a performance and when holding an instrument. Better training is essential. Musicians need to spend time getting used to rehearsing and performing with custom-moulded earplugs fitted until the attenuated music sounds normal. If earplugs are worn throughout a performance, the fact that they are more difficult to fit than standard earplugs will no longer be a problem. Any training on custom-moulded earplugs should also include a reminder that the ear-moulds do not last forever. They need checking after 4 to 5 years because over time the ear-mould material

may degrade and the user's ear may change shape. Both of these factors will affect how the earplug seals the ear and therefore the performance of the earplug.

5.6.6 Self-employed musicians

None of the self-employed musicians interviewed knew that major changes to current noise legislation were imminent for people working in the music and entertainment industry. [The interviews were carried out in 2007 before the new noise legislation came into force.] Consequently, they had no idea what they would be expected to do after April 2008. It is also clear that musicians using in-ear monitors need information on what these devices can do and how they can be used with other equipment to limit noise exposure, and they also need details of reputable suppliers, and typical costs. Simple, clear and practical guidance specifically for self-employed musicians is needed.

5.6.7 Other methods for controlling noise exposure

The musicians identified a range of control methods that have been used to limit noise exposure. These include rotating players within the orchestra, using acoustic screens/podiums/risers, increasing the separation between players, and playing in acoustically treated rooms that are large enough to accommodate all of the musicians. Many of the musicians seemed to think that the most effective way of controlling noise exposure was to increase the separation between individual musicians or sections. Unfortunately most reported that this was not possible because of space limitations in many orchestra pits and studios. Methods for reducing noise exposure should be given consideration when designing new studios, theatres, and venues or when carrying out major refurbishments of existing venues.

6 CONCLUSIONS

Musicians are exposed to high levels of noise, which could cause permanent hearing damage with prolonged exposure. The requirements of the Control of Noise at Work Regulations 2005 came into force in April 2008 in the music and entertainment industry. This legislation introduced similar action and limit values for employers as previous noise legislation but at lower levels of noise exposure. Employers have a duty under this legislation to prevent hearing damage and one of the methods used for controlling noise exposure is the use of appropriate hearing protection.

Semi-structured telephone interviews were conducted with nineteen musicians between June and October 2007 to gain an understanding of their attitude towards using hearing protection, and on the performance and usability of available hearing protectors. Although the sample was small it represented well the different types of instruments played, how long the musicians had played professionally, and the range of work experiences. The majority interviewed were classical musicians playing in large orchestras. However, the views of three freelance percussionists and two military band players provided some insight into the experiences of other types of musicians, playing different styles of music and in different venues.

Information from musicians and hearing protector manufacturers and suppliers showed that conventional (standard) hearing protectors often provide too much attenuation for musicians. In addition, because they are designed to provide high levels of high frequency attenuation, their use can result in musicians' mishearing or overplaying to compensate for the lack of high frequency sound heard through the protectors. Musicians are most likely to wear conventional hearing protectors when they are exposed to very loud music generated by other musicians. Conventional foam and flange earplugs are most commonly used because they are easy to fit during a performance, and they are often readily available, for example from dispensers located at the entrance to the studio or stage.

Premoulded musicians' earplugs provide moderate attenuation but preserve sound quality. They are a relatively inexpensive off-the-shelf earplug, and are reusable if kept clean. This type of protector can improve sound quality for those musicians working with or around amplified sound.

Custom-moulded musicians' earplugs use interchangeable filters to offer different levels of protection (between 9 and 25 dB), and they have attenuation characteristics that follow the natural frequency response of the open ear but at a reduced level to preserve sound quality. These earplugs are also unobtrusive, which is perceived as being an advantage for the audience. Custom-moulded earplugs are expensive, and more likely to be used by musicians whose employers provide them free of charge. Despite improved sound quality, orchestral musicians do not believe they can play properly when wearing custom-moulded protectors. However the improvement they provide to sound quality does mean that musicians are likely to prefer this type of protector when listening to other musicians during loud performances. Custom-moulded earplugs are perceived as difficult to fit, especially during a performance. In practice the musicians have two problems: fitting the earplugs while also keeping hold of their instrument and having very little time within a piece of music to fit the earplugs.

Musicians are reluctant to wear any type of hearing protection when playing solo or exposed pieces of music, which require them to play at the highest possible standard. Musicians believe that if they cannot hear the sound generated by their own instrument properly, they will not be able to make fine adjustments to their playing, control how loud or soft they play, or play in

tune with other players with any confidence. Principal musicians, and woodwind and brass musicians, are likely to be the most resistant to wearing hearing protection.

Custom-moulded vented earplugs are available. They are designed to provide significant high frequency attenuation and very little low frequency attenuation. A hole through the length of this type of earplug means that there is very little occlusion effect provided that the ear-mould has been taken and manufactured to a high standard. These earplugs may be useful for musicians who play low frequency instruments, and for those who blow into their instrument (eg woodwind and brass players). However none of the musicians interviewed for this study were aware of, or used, custom-moulded vented earplugs.

In-ear monitors allow musicians to control the mix and overall loudness of their own voice and instrument. However in-ear monitors are capable of producing very high noise levels. It is also very difficult to predict the actual output from these devices because they are amplified through a variety of monitor boards, transmitters and belt-packs, all supplied by different manufacturers. Where overall noise levels are not controlled (which can happen at some large venues), in-ear monitors provide musicians with a method for controlling the level of incoming sound when used with a personal mixing desk, and the earpiece provides some isolation. There are currently no standard tests governing the performance of custom-moulded electronic earplugs.

7 RECOMMENDATIONS

A good education programme is needed for both employed and self-employed musicians. It should include information on the requirements of current noise legislation clearly identifying employer's and employee's responsibilities, typical noise exposures and the associated risk to hearing, the signs and symptoms indicative of hearing damage, and the types of hearing protectors available and the advantages and disadvantages of each type. Training on the selection and proper use of hearing protection is essential to ensure that the use of hearing protection is an effective method for controlling musicians' noise exposure.

Musicians need to spend time getting used to practicing, rehearsing and performing with earplugs until the attenuated music sounds normal, especially with musicians' earplugs which are designed to preserve sound quality. If earplugs are worn throughout a performance, the fact that they are difficult to fit or that fitting them during a performance spoils the continuity of the music for the musician, will no longer be a problem.

It is essential that musicians are educated in the safe use of in-ear monitors, which should include providing information on what these devices can do, how they can be used with other equipment to limit noise exposure, details of reputable suppliers, and typical cost. Any noise reduction claims made by in-ear monitor manufacturers and suppliers must be substantiated with evidence, for example BS EN 352 attenuation data.

It is essential that suitably qualified professionals take and manufacture all ear-moulds to a high standard. Poor ear-moulds can result in earplugs that are uncomfortable, or that block out too much sound. Similarly, it is important that musicians are provided with appropriate filters so that their earplugs do not provide them with either too much or too little protection. In accordance with HSE guidance, fit tests should be carried out before custom-moulded earplugs are put into use to ensure that they fit properly and are comfortable.

Ear-moulds should be checked after 4-5 years. Over time the earplug material may degrade and the user's ear may change shape; both of these factors may compromise the performance of the earplug. All hearing protectors should be CE marked and supplied with attenuation data according to BS EN 352, which describes and verifies the performance of the protector.

A range of noise control methods is available for reducing musicians' noise exposure. These include the use of screens and risers, regularly rotating musicians within the orchestra, increasing the separation between players, and sound limiting on electronic systems. However reflected sound makes the use of screens unpopular, and the lack of space in many orchestra pits and studios makes it difficult to implement many of the other control measures. It is essential that methods used to control noise be given consideration when designing or refurbishing venues in which live music is played, so that musicians do not have to rely on hearing protection to control their noise exposure.

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APPENDIX A: LITERATURE SEARCH STRATEGY

The literature for the review reported in Appendices B and C was identified from the following bibliographic databases:

- Medical databases – Embase, Psychinfo, Medline
- Engineering databases – Compendex, Inspec, ANTE
- Health and safety at work databases – OSH-ROM (containing HSELINE, NIOSH, CISDOC, RILOSH, CCOSH, OSHLINE), HEALSAFE, RoSPA
- World Wide Standards – HIS

The following keywords were used: musicians, classical, orchestral, symphony, concert, rock, pop, jazz, noise, levels, exposure, noise-induced hearing loss, audiometry, tinnitus, hearing disorders, sound measurements, dosimeters, hearing protectors, earmuffs, earplugs, comfort, usage, attenuation data, attitude, behaviour, comfort, minimum attenuation requirements, flat frequency response, integral communication system, quality, attenuated music speech.

A significant number of papers referenced in this review were found within other papers identified during the original search.

The search was restricted to those papers written in English within the last 5 to 10 years.

An extensive search of the internet was conducted to identify hearing protectors designed for musicians.

Information was also obtained from telephone conversations with hearing protector manufacturers/suppliers and telephone interviews with professional musicians.

APPENDIX B: MUSICIANS' NOISE EXPOSURE

Chasin (1999) highlighted both the similarities and the important differences between music and noise. Both spectra are relatively broadband, with similar crest factors and a similar range of average sound pressure levels. However music is significantly more intermittent than industrial noise: it has loud intense periods followed by quieter, or in some cases completely silent, periods. It is this intermittence that many researchers feel is the reason why exposure to music may be slightly less damaging than an equivalent industrial noise exposure. It is thought that the stapedial reflex provides a significant amount of protection from noise or music when exposure is intermittent. This reflex is due to the contraction of a muscle in the middle ear that contracts in response to loud sounds. This contraction pulls on the middle ear bones, temporarily making it harder for sound to be transmitted to the inner ear.

A wide range of noise levels is reported in the literature in relation to the levels of noise that classical (orchestral) and rock/pop musicians are typically exposed to. Table B1 contains a summary of this noise data with details of the source of this information.

Table B1: A-weighted noise data for musicians

Author	Year	Type of music	Instrument	¹A-weighted noise data dB
Butterfield	2006	Live indoor events	Drum, bass guitar, guitar	101 – 105
Einhorn	2006	Rock/pop Orchestra Jazz/blues		120 – 130 82 – 112 80 – 101
Hain	2006	Orchestral	Woodwind	112
Schmuziger et al	2006	Rock/pop	Guitars, bass, percussion, trombone, keyboard	100 – 105
Hagberg et al	2005	Orchestral	Woodwind Brass Percussion	95 92 – 94 95
		Rock/jazz		91 – 95
Peters et al	2005	Orchestral Rock		80 – 100 90 – 105
Kahari et al	2003	Rock/jazz	Drum Bass	101 – 109 106 – 115
Laitinen et al	2003	Orchestral	Woodwind Brass Percussion	95 92 – 94 95
Lee et al	2003	Orchestral	Strings Woodwind Brass Percussion Conductor	84 – 90 87 – 90 90 – 93 85 – 87 82
Eaton et al	2002	Orchestral	Strings Woodwind Brass	85 – 89 91 – 92 93 – 95
Babin	1999	Orchestral		84 – 101

Author	Year	Type of music	Instrument	¹ A-weighted noise data dB
Groothoff	1999	Rock/pop		98 – 106
Obeling et al	1999	Orchestral	String	75 – 91
			Woodwind	85 – 94
			Brass	86 – 95
			Percussion	84
Teie	1998	Orchestral	Strings	75 – 103
			Woodwind	80 – 112
			Brass	85 – 114
			Percussion	90 – 92
Gunderson et al	1997	Rock/jazz	Amplified music	95 – 107
Early et al	1996	Orchestral		86 – 108
Palin	1994	Orchestral	Woodwind	92 – 94
			Brass	92 – 93
Killion	1993	Orchestral		105
Royster et al	1991	Orchestral	String	78 – 100
			Woodwind	82 – 96
			Brass	86 – 98

¹ This data includes reported average noise levels and daily, weekly and annual time-weighted noise exposure levels (discussed further in this section)

Levels for groups of instruments have been combined. The instruments groups defined in Table B1 include the following instruments:

- Strings: violin, viola, cello, double bass
- Woodwind: oboe, clarinet, bassoon, flute
- Brass: trumpet, trombone, horn, tuba
- Percussion: full drum kit, glockenspiel, tympani, gongs, etc

The data in Table B1 shows that musicians are exposed to a very wide range of levels, even for similar instrument types. The data was combined to give a rough idea of the difference between rock/pop and classical music levels. From the range of noise values in Table B1, the minimum levels reported for each type of music were combined to give mean and standard deviation values; similarly the mean and standard deviation values were obtained for the maximum levels reported. The range of rock/pop A-weighted noise levels was between 88 and 117 dB, and the range of classical music A-weighted noise levels was between 80 and 110 dB; where the lower range values are mean levels minus one standard deviation, and the upper range values are mean levels plus one standard deviation. These estimated ranges show that rock/pop music noise levels are higher than classical music noise levels.

The spread of reported noise levels for both rock/pop and classical music is similar; the difference between the minimum and maximum estimated noise levels is approximately 30 dB. There are several reasons why there is so much variation in the reported noise levels. The data reported in many studies were measured using dosimeters attached to individual musicians, microphones located in fixed positions, or a mixture of the two methods. It is not clear from the majority of published reports where the microphones were placed, yet this can have a significant effect on the measured levels. Butterfield (2006) reports discrepancies between dosimeter and fixed microphone measurements, and between different microphone positions for dosimeter measurements. Noise levels measured with the dosimeter microphone attached to the wearer's

collar can be up to 5 dB higher than when the microphone is fixed to the point of the shoulder. The location of fixed microphones within the orchestra (eg at the side, front, back) can also result in measured noise levels varying by between 4 and 6 dB (Palin, 1994).

The acoustic environment in which the levels are measured can also have a significant effect on the measured noise. Higher noise levels are likely to be measured for orchestral musicians playing in a deep orchestra pit (effectively a confined space) than for those playing on a large open stage; Palin (1994) observed increases of up to 3 dB. Early et al (1996) showed that musicians can be exposed to high noise levels during practice sessions and recommended that attention should be given, in particular, to small practice rooms where the sound can reach excessive levels due to reflections if the room is reverberant.

The noise levels will also depend on the type of music being played. The overall noise levels generated during rock/pop concerts tend to be higher than those generated during classical concerts. The dynamic range of rock/pop is generally smaller than that of classical music. Rock/pop music typically gets loud and stays loud, so that there is not so much variation in the measured noise levels. It also tends to be louder because there are not as many quiet periods in the arrangements. By comparison, classical music has a huge dynamic range comprising of very loud periods followed by very quiet or even silent periods. For classical music, the noise levels will depend on the type of classical music played. Modern classical music is more dynamic and generates higher noise levels than older pieces of music, partly due to the character of the composed music and partly due to increased use of percussion and brass instruments (Ostri et al, 1989). Differences of up to 10 dB (Laitinen et al, 2003; Lee et al, 2003) have been reported due to the playing of different pieces of music, for example *Madame Butterfly* and *The Italian Girl in Algiers*. Some musicians have also reported that there is a trend for conductors to push the orchestra to perform intensely and loudly (Kahari et al, 2001) in an effort to attract audiences.

The noise levels measured for individual musicians are highly dependent on the type of instrument they play and also where they sit in the orchestra. For example, higher noise levels will be measured in the left ear of violin and viola players compared with the right ear, and for flute players higher levels will be measured in the right ear compared with the left ear (Kahari et al, 2001), probably due to asymmetrical noise exposure from their instruments. Musicians sitting close to the brass and woodwind instruments will be exposed to higher A-weighted noise levels (80 – 114 dB Table B1) compared to musicians sitting near the string instruments (75 – 103 dB Table B1). Henahan (1985) referred to those musicians who have to sit directly in front of brass or percussion sections as “unfortunately positioned” because of “instrumental din”!

Another reason such a wide range of noise levels has been reported may be due to the fact that authors are measuring and reporting different quantities, for example equivalent continuous sound levels (L_{Aeq}), instantaneous sound pressure levels, and time-weighted noise exposures. While some authors clearly define the parameters that have been measured, including the dosimeter’s exchange rate setting (typically 3 dB in UK and Europe, and 5 dB in the USA), many do not. Table B2 contains a summary of the daily, weekly and annual noise exposure levels that have been reported in the reviewed literature. These exposures take into account the level of noise exposure and the typical durations.

Table B2: A-weighted noise exposure levels for musicians

Author	Year	Type of music	Typical exposure duration	Type of noise exposure	A-weighted noise exposure dB
Lee et al	2003	Orchestral	300 hrs/year	Annual	74 – 85
Laitinen et al	2003	Orchestral	1500 hrs/year	Annual	83 – 95
Eaton et al	2002	Orchestral	15 hrs/week over 8mth annual season	Annual	84 ± 1
Early et al	1996	Orchestral	4 – 8 hrs/day	Daily	86 – 108
Royster et al	1991	Orchestral	15 hrs/week	Daily	75 – 95
Kahari et al	2003	Rock/jazz	1 – 2 hrs/day	Daily	95 – 105
Gunderson et al	1997	Rock/jazz	-	Daily	92 – 100
Schmuziger et al	2006	Rock/pop	5 hrs/week	Weekly	100 – 105
Butterfield	2006	Rock/pop	-	Daily	101 – 105
Groothoff	1999	Rock/pop	-	Daily	98 – 106

For the music and entertainment industry in the UK, exposure action values for an individual's daily personal noise exposure are currently set at 80 dB and 85 dB, A-weighted. Table B2 shows that A-weighted noise exposure values reported for rock/pop/jazz musicians are between 92 and 106 dB. These exceed the exposure action values defined in current legislation, which suggests that there may be a risk of hearing damage for these musicians.

The A-weighted daily personal noise exposure values reported for orchestral musicians are between 75 and 108 dB. Annual personal noise exposure values take into account the large variation in the number of hours worked over a year, for example there may be a seasonal element for the music programme of some orchestras. The annual A-weighted personal noise exposure values shown in Table B2 are therefore lower, ranging from 74 to 95 dB. These exposures still suggest that some orchestral musicians are exposed to levels of noise that may result in hearing damage. An important point to highlight is that most of the reported data is for working hours that only includes group rehearsals and performances. It does not include the noise exposure from solo practices, teaching and off-the-job exposure to music, for example freelance work with another group of musicians. Laitinen (2005) suggests that the amount of time musicians spend practicing on their own could be of the same order of magnitude as reported performance times. It is essential that all sources of noise exposure (eg solo practices, group rehearsals and performances) be taken into account when assessing the risk to musicians' hearing.

APPENDIX C: MUSICIANS' HEARING

Hearing disorders among musicians

Two types of hearing damage can occur as a result of exposure to noise. Acoustic trauma is an immediate, severe and permanent hearing loss that can occur following exposure to a very loud noise (eg gunshot or explosive). This type of exposure causes physical damage to the structures of the inner ear. The second type of damage is a gradual hearing loss that occurs as a result of prolonged exposure to loud noise. It is referred to as noise-induced hearing loss. The level and duration of exposure, the frequency characteristics of the noise, and individual susceptibility determine the degree of hearing loss. Gradual hearing loss resulting from chronic exposure to music is termed music induced hearing loss (MIHL) (Einhorn, 2006). Other hearing disorders associated with noise induced hearing damage exist among musicians. These include:

- Tinnitus – the perception of sound in the absence of any sound, ie ringing in the head or ears
- Recruitment – reduced dynamic range of hearing
- Hyperacusis – extreme intolerance to everyday sounds
- Distortion – sounds are heard but lack clarity
- Displacusic – sounds are perceived as being of a different pitch than they actually are

Incidence of hearing loss among musicians

The most common method of assessing musicians' hearing loss is to compare age- and gender-adjusted measured threshold levels against ISO 7029: 2000 reference data or another normal hearing non-noise exposed control group.

There are several very comprehensive reviews of the studies carried out to investigate hearing damage in classical musicians (Palin, 1994; Eaton et al, 2002). Table C1 contains a summary of the individual studies reviewed and the conclusions drawn from them. It also contains the results from the papers reviewed for this project on hearing loss in orchestral musicians, rock/pop musicians and percussionists.

Table C1: Summary of hearing loss studies between 1960 and 2006

Author	Year	Brief study details	Conclusions
ORCHESTRAL MUSICIANS			
Arnold et al	1960	30 pianists	Better hearing than that of average reference population
Flach et al	1967	277 orchestral musicians	No significant hearing loss compared with reference population
Westmore et al	1981	34 orchestral musicians	12% of sample had 20 dB hearing loss at 4 kHz but not statistically significant
Axelsson et al	1981	139 orchestral musicians	58% of sample had hearing loss >20 dB, could be due to noise exposure or ageing, poorer hearing in brass and woodwind players
Karlsson et al	1983	417 orchestral musicians	No increased risk of hearing loss compared with screened and non-screened non-noise exposed populations, risk of NIHL nil or negligible
Johnson et al	1985	62 orchestral musicians	No significant hearing loss compared with unscreened non-noise exposed population
Johnson et al	1986	60 orchestral musicians	No significant difference between hearing levels of musicians and non-musicians, both groups showed similar age effect at high frequencies
Ostri et al	1989	95 orchestral musicians	Slightly poorer hearing than reference population
Royster et al	1991	59 orchestral musicians	Better than average hearing compared to unscreened non-noise exposed population, slightly poorer hearing compared to screened non-exposed population, high freq notch suggestive of noise-induced hearing loss in 53% of ears
McBride et al	1992	63 orchestral musicians	No statistical difference between hearing of musicians exposed to high and low levels of music
Kahari et al	2001	140 orchestral	No severe hearing loss, high-frequency

Author	Year	Brief study details	Conclusions
		musicians	notch suggesting some noise damage, percussion and woodwind poorest hearing levels
Eaton et al	2002	53 orchestral musicians	No significant difference between hearing levels of musicians and unscreened non-noise exposed population, high frequency notch in 25% suggestive of noise damage
ROCK/POP/JAZZ			
Cunningham et al	2006	400 percussionists	Poorer hearing thresholds for musicians compared to non-exposed reference population, prevalence of hearing loss 39% among percussionists (9% among general population)
Kahari et al	2003	139 rock/jazz musicians	No significant difference between hearing levels of musicians and non-exposed normal population; higher rate of incidence of hearing disorders, 43% tinnitus, 39% hyperacusis
Schmuziger et al	2003	42 pop/rock musicians	Slightly poorer than hearing of control group, 17% tinnitus, 26% hyperacusis, significant effect on hearing levels due to use of hearing protection

It is very difficult to draw conclusions about the incidence of hearing damage among musicians based on the studies reviewed here. For orchestral musicians, the published literature identified:

- Seven studies that concluded there was no significant difference between the hearing threshold levels of musicians and non-noise exposed reference populations;
- Two studies that found musicians with better hearing than the reference population; and
- Four studies that concluded that musicians have slightly poorer hearing thresholds than non-noise exposed reference populations.

Similar results were found for rock/pop musicians: one study concluded that there was no significant difference between the hearing threshold levels of musicians and non-noise exposed reference populations; and two studies observed musicians with slightly poorer hearing thresholds compared to non-exposed reference populations.

The range of conclusions from different published studies makes it very difficult to say for certain whether musicians' noise exposure is sufficiently high or prolonged to cause hearing damage. In the studies that identified some hearing loss, it was generally in the form of a high

frequency notch (that may or may not be related to presbycusis) or raised hearing thresholds. However raised thresholds were generally not significant in terms of associated hearing damage, when compared to the threshold levels used to define hearing loss. Several definitions for hearing loss have been reported in the literature: Cunningham et al (2006) defined hearing loss as hearing thresholds equal to or greater than 25 dB at two or more frequencies or equal to or greater than 30 dB at one frequency in one or both ears; Kahari et al (2001) defined normal hearing as pure-tone thresholds equal to or less than 20 dB at the frequencies between 250 Hz and 8 kHz.

Cunningham et al (2006) measured mean auditory threshold levels for percussionists that were 5 to 11 dB higher than the reference group. However, these raised levels were less than 20 dB, suggesting only a slight hearing loss. Schmuziger et al (2006) also measured significant but small hearing losses in a group of pop/rock musicians; hearing thresholds were raised by up to 7 dB. Interestingly in this study, hearing loss was minimal in musicians who always wore hearing protection.

Palin (1994) concluded that conflicting conclusions could be partly due to the poor design of many of the studies. Reviewing the literature has identified the following problems with hearing loss studies, which must be addressed in future hearing loss studies:

- There is no universal definition for hearing loss. No definition was given in some studies, which partly explains the different conclusions reached by some studies.
- Not all possible risk factors for noise-induced hearing loss are identified for the musicians taking part in the studies: age, sex, instrument, position of seating in orchestra, practice outside orchestra, noise exposure other than classical music (eg hobbies, previous occupational noise exposure).
- Exclusion criteria such as pre-existing ear pathology, family history of hearing loss, use of ototoxic drugs are not identified.
- Hearing threshold levels are not measured at all the relevant frequencies.
- No record of when audiometry is carried out (hearing thresholds should be measured before a rehearsal or performance to ensure that there is no temporary hearing threshold shift due to music exposure).
- Sample sizes are generally small, which makes it difficult to assess statistical significance.

Although it is not clear whether exposure to music can cause significant hearing loss, several authors have reported higher levels of hearing disorders such as tinnitus and hyperacusis, especially among rock/pop musicians. Incidence rates for tinnitus were between 17% and 54 % (Schmuziger et al, 2006; Hoffman et al, 2006; Kahari et al, 2003); incidence rates for hyperacusis were between 26% and 39%. Kahari et al (2003) found hearing disorders in 74% of rock/pop musicians, although there were no significant hearing losses. The reason for this high rate of hearing disorders, and low rate of hearing loss may be due to damage mechanisms that have their origin in parts of the auditory system other than the cochlea.

Pure tone audiometry is traditionally used to assess whether a person is suffering from a hearing loss, and it is the basic tool in the diagnosis of congenital or acquired hearing loss. However several authors (Chasin, 1999; Kahari et al, 2001; Cunningham et al, 2006) have suggested it may not be a sufficiently sensitive test on its own to detect the early stages of hearing disorders in musicians and to allow a full assessment of hearing. A thorough hearing assessment for

musicians is recommended, which includes extended measurements such as speech in noise, uncomfortable loudness level in the case of pure tones, and otoacoustic emission tests, along with assessment of other hearing disorders.

[Note: Otoacoustic emissions indicate the health of the sensory cells. Changes in otoacoustic emissions can potentially provide the first indication of sensory cell damage, even before the pure-tone audiogram shows any significant decrease in auditory sensitivity.]

APPENDIX D: TOPICS COVERED DURING TELEPHONE INTERVIEWS WITH MUSICIANS

The purpose of this telephone interview is to identify the type of hearing protection (if any) musicians are currently using; musicians' attitudes towards hearing protection and the factors musicians think are important in choosing hearing protection.

Work history

- What area do you currently work in (including instruments played)?
- Give a brief description of your work history (eg teaching, freelance work, contract work)
- How long have you been working in the music industry?
- Give details of any previous relevant occupations.
- Are you self-employed?

Noise exposure

- How would you rate your current noise exposure (insignificant, excessive, exposed to a lot of noise every so often, exposed to a little very regularly, etc)?
- Describe type of exposure, eg typical duration in hours per session, loudness, frequency (no. of day/weeks), source of noise, etc
- Has your noise exposure been assessed – any idea of the level of noise you are typically exposed to?
- Have you experienced any temporary deafness (noises sounding very quiet following exposure)?
- Have you had any hearing tests (audiometric testing)?
- Do you have diagnosed hearing loss, ringing noises in the ears, etc?

Hearing protection

- Do you wear hearing protectors? If so, what type (eg standard earplugs, musicians' earplugs, ear muffs, in-ear monitors, etc)?
- Why did you choose this particular type of hearing protection?
- If you don't wear hearing protectors, why not?
- Did you choose to wear hearing protection, or was it required (eg by employer)?
- Can you do your job effectively while wearing hearing protection? If not, why not?
- Have you received any training on how to select, fit and care for earplugs?

Factors that may influence hearing protection use/choice

I have put together the following list of factors that I think may be important when deciding what hearing protection to use. These are: comfort; attenuation requirements; flat frequency response (ie those designed to reduce muffle effect you sometimes get with conventional hearing protectors); integral communication system; the quality of the attenuated sound (music and speech); and cost.

- Which of these factors are important to you when deciding whether or not to use hearing protection?
- Do you think I've missed any important factors out – based on your own experiences?
- Do you have any comments on any of these issues that relate to your particular circumstances?
- What do you think are the most/least important factors when deciding whether or not to use/choose a particular type of hearing protection?

Finally, do you have any other comments?

Musicians' hearing protection

A review

The music and entertainment industry is unique in that high noise levels are often regarded as an essential element for the enjoyment of people attending concerts and live music events. However, there is a risk of hearing damage for people working in the music and entertainment industry, including musicians. One of the methods used to reduce noise exposure is the use of appropriate hearing protection. Many different types of hearing protection have been marketed for musicians including premoulded earplugs, custom-moulded earplugs and in-ear monitors. In order to support the Health and Safety Executive's (HSE) understanding of this issue, the types of hearing protection available to musicians were identified. Telephone interviews were then conducted with nineteen professional musicians to collect information on: the type of hearing protection (if any) musicians are currently using; musicians' attitudes to hearing protection including whether they think it is, or it can be, effective and whether it allows them to do their job effectively; and the factors musicians consider important when choosing hearing protection.

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