London South Bank University
Faculty of Engineering Science and the Built Environment

MSc in Environmental and Architectural Acoustics

INVESTIGATION INTO NOISE LEVELS PRODUCED BY PERSONAL MP3 PLAYERS

P J Wash

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A project in partial fulfillment of the requirements of the degree of Master of Science in Environmental and Architectural Acoustics

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1.0 BACKGROUND AND INTRODUCTION

The risk of recreational noise exposure such as amplified music played at concerts or in nightclubs has been well documented for over the last 40 years; however noise exposure from other recreational sources such as that from personal stereos has been less documented.

The advent of Mp3 players such as the Apple iPod, with its long battery life and huge memory, has made ‘music on the move’ inherently popular with millions of people in the UK alone. Due to the meteoric rise of the Mp3 player, many recent stories in the press have discussed the increasing use of personal stereos, mainly focusing on the levels at which some people (particularly teenagers) listen to music and the possible health implications. It has been argued that the levels at which people listen to music is a personal choice and that in most cases the majority of people are responsible enough to know what is ‘too loud’. However, what if the levels set by the user are strongly influenced by another variable such as background noise? The sight of commuters listening to music is a familiar scene on the London Underground, where background levels can sometimes be as high as a busy bar playing amplified music. If a commuter listens to their Mp3 player whilst exposed to these levels of background noise, how high will the volume be set to overcome the background noise? More importantly, are these levels a cause for concern with regards to personal health? Bearing in mind that current (2005) UK Noise at Work Regulations set a maximum exposure limit of 87 dB(A) averaged over an 8 hour working day, it seems comprehensible that these levels could be exceeded. If this is the case, it could be argued that a commuter listening to their Mp3 player during their commute to and from work could be more at risk to hearing damage than a road-worker using a pneumatic drill who, under law, uses appropriate hearing protection.

This investigation aims to measure the output levels of an Mp3 player used by 30 test subjects when exposed to a typical continuous background noise under controlled conditions. The output level will be measured with and without a background noise present to enable a comparison to be made with regards to the effect background noise has on the user defined output level. The full methodology can be found in Section xx.

2.0 WORKINGS OF THE HUMAN EAR

2.1 Components

The human ear has three main components; the outer, middle and inner ear. Figure 1 below shows a basic diagram of the human ear.

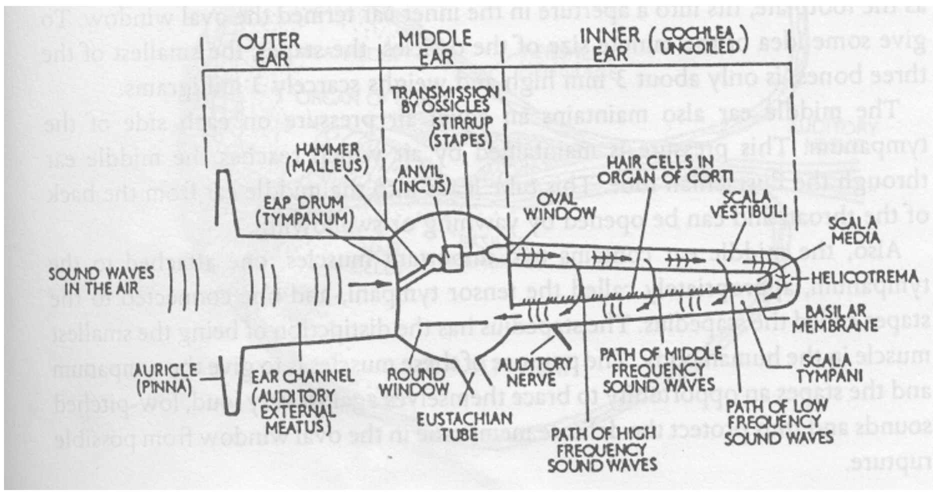

Figure 1 – Simplified diagram of the human ear[1]

2.1.1 <u>The outer ear</u>

The outer ear consists of the auricle (sometimes known as the pinna, which is situated externally) and the ear canal, otherwise known as the external auditory meatus. The auricle provides amplification of sound waves into the ear canal and also provides the ability determine the direction of the sound being heard.

The ear canal is approximately 25mm in length, terminating at the ear drum or tympanum. The ear drum is approximately 10mm in diameter and roughly the same thickness as a sheet of newspaper[1]. The eardrum is under high tension, for example a 'middle C' on a piano when played causes the eardrum to vibrate at a rate of 256 vibrations per second through a distance of 1 x 10-12 mm[1].

2.1.2 The middle ear

The small space between the ear drum and the inner ear houses a lever system of three bones called the ossicles. These bones provide a means of communication between the ear drum and the inner ear, transmitting the pressure changes incident on the ear drum. These three bones are known as the hammer, anvil and stirrup; otherwise known as the malleus, incus and stapes respectively. The smallest of the three bones, the stirrup, is approximately 3mm high and weighs approximately 3mg[1].

Figure 2 below shows the configuration of the ossicles with respect to the inner and outer ear.

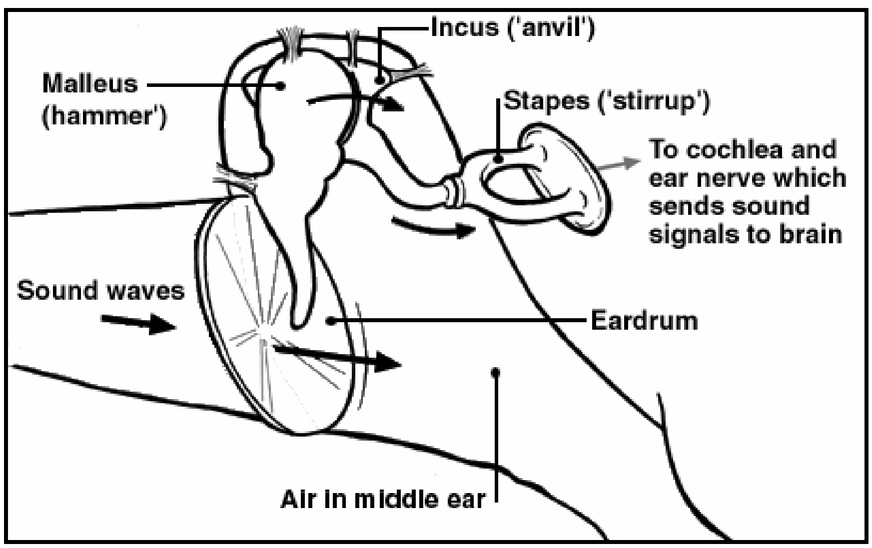

Figure 2 – Simplified diagram of the ossicles[2]

The Eustachian tube provides the middle ear with air from the back of the throat, which is used to maintain pressure each side of the ear drum. The middle ear also contains two muscles, the tensor tympani (connected to the eardrum) and the stapedius (connected to the stapes or stirrup) which provide a feedback mechanism to brace the eardrum and stirrup against very loud noise levels in order to try and prevent damage caused by excessive movement.

2.1.3 The inner ear

The inner ear contains two main components, one for hearing (the cochlea) and one for the control of balance. For the purpose of this project, only the hearing component of the inner ear has been studied.

The cochlea is a coiled tube approximately 30 - 35mm in length (uncoiled) and approximately 5mm in diameter, divided into two sections filled with fluid known as perilymph. The sections are divided by a bony shelf and a membrane, known as the basilar membrane, which has a thickness of approximately 0.001mm at the basal end and 0.005mm at the apex[1].

The upper section, known as the scala vestibuli, is connected to the middle ear via the oval window. The lower section of the cochlea, known as the scala tympani, connects to the middle ear via a different aperture known as the round window.

The upper section also contains an ancillary section known as the scala media, separated by a further membrane known as Reissner's membrane. The scala media contains the organ of Corti, where sound waves are converted into electrical impulses. This organ contains approximately 23,000 hair cells arranged in four outer rows and one inner row of pillars or rods, with between 25,000 and 30,000 auditory nerve fibres at the base the hair cells (just over one nerve fibre per hair cell)[1]. The ends of the hair cells pass through recticula lamina membrane and embedded in a thicker membrane which covers the organ of Corti. These fibres twist together, leaving the cochlea to join the temporal portion of the brain. The 'twisting' together of the fibres is known as the auditory nerve.

A cross section of the cochlea can be seen in Figure 3 below.

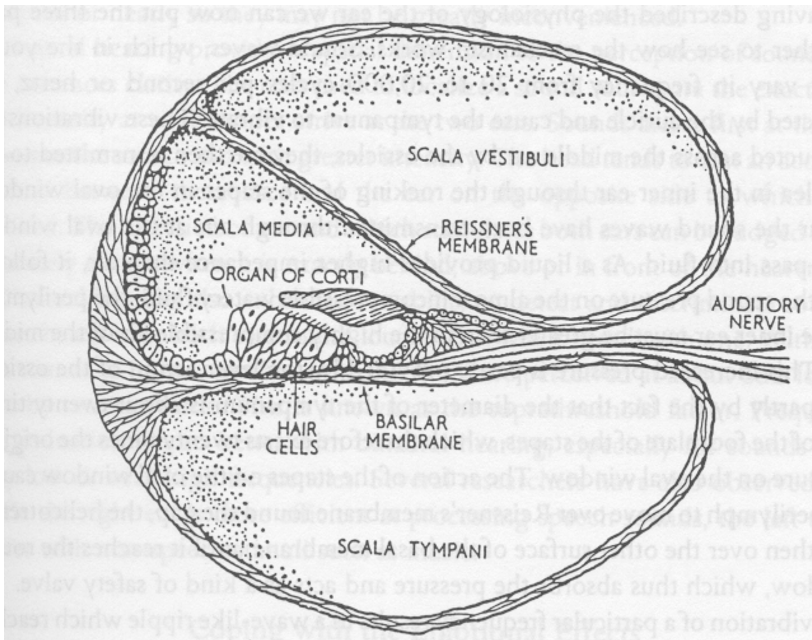

Figure 3 – Cross-section of the cochlea

2.2 How the ear works

Sound waves, which, by definition are pressure changes in the air, cause the eardrum to vibrate. The vibrations from the eardrum are transmitted via the ossicles of the middle ear to the oval window. The vibrations are then able to enter the fluid inside the cochlea at an increased pressure. This increased pressure is partly due to the lever action of the ossicles, the greater impedance of the fluid (perilymph) compared to that of the air in the middle ear and also the fact that the eardrum is approximately twenty times the size of the base plate stapes. This adds up to a 20:1 amplification ratio of the pressure between the ear drum and the oval window.

Each frequency incident at the oval window travels through the perilymph at a specific distance, dependent on the frequency. This means that high frequencies terminate nearer the oval window and low frequencies terminate further towards the apex of the basilar membrane. The movement causes shearing between the hair cells present in the organ of Corti and the covering membrane, which in turn causes an electro-chemical reaction in the nerve fibres. The electro-chemical reaction is then transmitted to the brain via the auditory nerve, where each individual frequency is de-coded into what is perceived sound.

The whole operation is completed in around three-hundredths of a second, enabling the human ear to distinguish an estimated 350,000 distinct sounds[1]. Lysons describes the ossicles as a 'mathematically perfect transmission system' and the actions of the oval and round windows as an 'ideal hydraulic system'.

Such a delicate and intricate system is therefore also a very vulnerable system that is nearly always taken for granted. It is quite easy to contemplate that disruption to any part of this system will have a ‘knock-on’ effect to the remaining part of the hearing process.

3.0 CAUSES OF HEARING LOSS

There are three main categories of hearing loss – *conductive* loss, *sensorineural* loss and *mixed* hearing loss. An explanation of each is detailed below:

3.1 Conductive loss

This is caused by damage to the outer or middle ear such as an obstruction i.e. excessive wax or a foreign body, damage to the ossicles (Otosclerosis), or an accident i.e. a ruptured or perforated eardrum. Symptoms of conductive hearing loss include a reduced speaking volume, due to the fact that the person affected can hear their own voice through bone conduction.

Inflammation of the middle ear, known as otitis media, is very common and can be treated with anti-biotics. However, if not treated the inflammation and excessive fluid produced in the middle ear can put pressure on the ear drum to the point of rupture. In many cases, particularly with young children, the infection may be cured, leaving sterile fluid present in the middle ear. This sterile fluid gradually becomes thicker, causing what is known as 'glue ear', resulting in hearing loss as the ossicles are impeded.

Otosclerosis, unlike otitis media is a condition that generally occurs in later life i.e. from young adulthood through to middle age. Here the ossicles are directly affected by a softening of the ear bone meaning the stapes becomes fixed to the oval window. The hearing loss caused by this disease deteriorates with age and often lead to tinnitus and is estimated to be twice as common in women as in men[1].

3.2 Sensorineural loss

Otherwise known as ‘perceptive loss’, this type of hearing loss is due to damage of the cochlea or nerve pathways to the brain. This can be caused by head injuries, virus or bacterial infections i.e. mumps and measles, excessive noise and old age (presbyacusis). Typical symptoms include the person affected speaking loudly and also discomfort felt towards loud sounds and speech.

Presbyacusis, otherwise known as ‘senile deafness’, occurs in the high-frequency range and worsens with age as the basal end of the cochlea deteriorates. The rate at which hearing deteriorates due to age varies from person to person and can be directly related to noise exposure, which is discussed later.

Meniere’s disease is a disorder that is known to be caused by a surplus of endolymphatic fluid in the inner ear. This disorder directly affects not only hearing but also balance, with sufferers experiencing extreme cases of vertigo.

Tinnitus can be defined as a *‘subjective experience of noise where there is no external stimulation’*[1]. It is often described as a ‘ringing’ or ‘roaring’ heard constantly, with the tone and volume varying with each patient. Sufferers of tinnitus generally find it more intrusive during the night-time when the background noise level drops. As a result, many sufferers use music or other sounds to mask their tinnitus during sleeping hours.

There are numerous causes of tinnitus, including obstructions to sound conduction i.e. perforated eardrum, pathological changes in the cochlea cells i.e. acoustic trauma and physical distortion of the cochlea system i.e. Meniere’s disease.

3.3 Mixed loss

This is quite simply where conductive and sensorineural hearing loss are present at the same time.

3.4 Summary

For the purpose of this study, emphasis will be placed upon hearing loss due to noise exposure, commonly known as noise induced hearing loss (NIHL), discussed in Section 4.

4.0 NOISE INDUCED HEARING LOSS (NIHL)

It is common fact that excessive noise exposure will lead to some form of hearing loss. The degree of hearing loss caused by exposure to excessive noise is dependent on the level of noise and the duration of exposure to the noise. In addition to this, damage to the cochlea is usually at a particular frequency or frequencies relating to the environment to which the subject is exposed. Many people are unaware that noise induced hearing loss is irreversible. In most cases noise induced hearing loss forms over a long period of time, meaning the effects are only apparent when any form of prevention is too late.

The aging process (Presbycusis) is also known to cause frequency degeneration of the cochlea, with the degeneration beginning at the higher frequencies nearest to the middle ear. This is one of the main reasons why many elderly people cannot distinguish between the 'p', 'c' and 't' sounds used in speech, making conversation difficult[3]. Figures 4 to 8 below show magnified images of dissected human cochlea for three people of varying ages and occupations.

Figure 4 shows the cochlea of a 24 year old male who had previously served in the armed forces driving a tank. Figures 5 and 6 show the left and right cochlea of a 72 year old male who has not been exposed to industrial noise but was a keen hunter. Figure 7 shows the cochlea of a 50 year old male who was exposed to industrial noise and also keen a hunter. Figure 8 shows the cochlea of a 92 year old female who has no history of noise exposure.

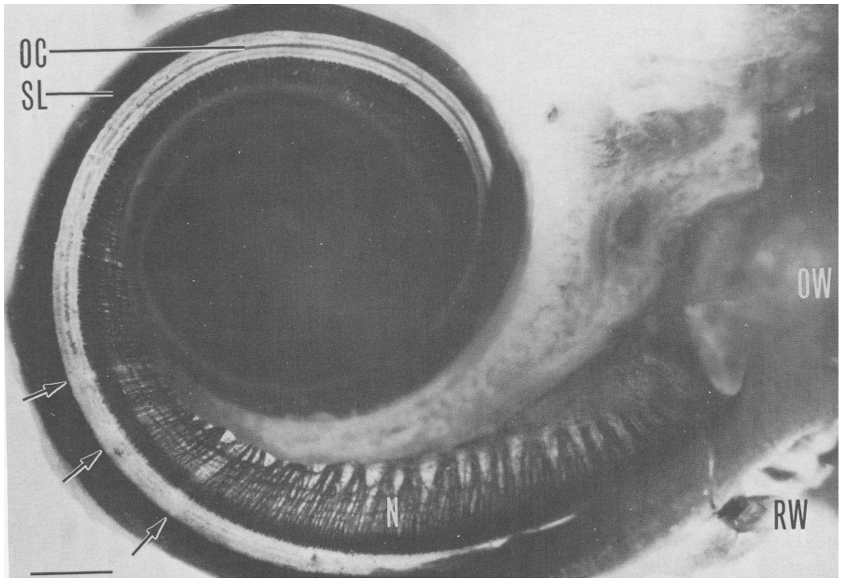

Figure 4 – Cochlea cross section, left ear, 24 year-old male, not exposed to industrial noise but a keen hunter[44]

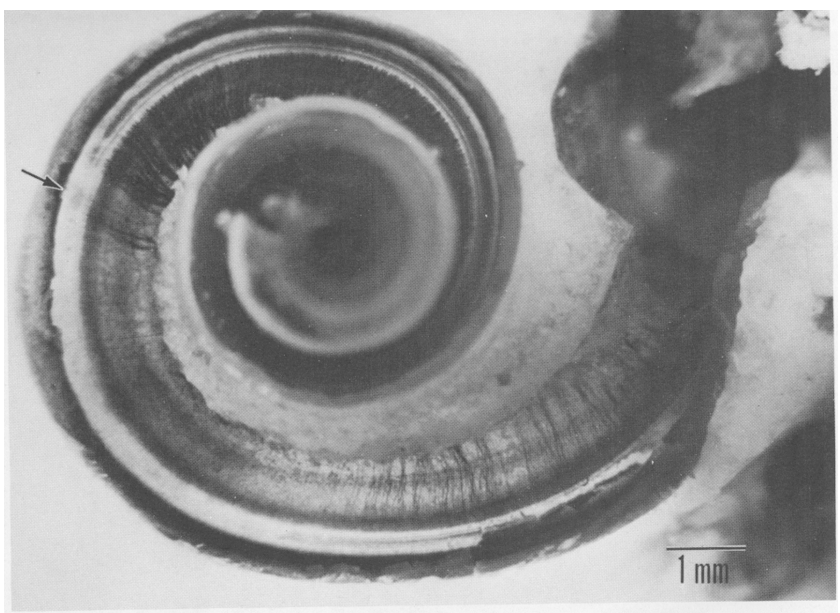

Figure 5 - Cochlea cross section, left ear, 72 year-old male, not exposed to industrial noise but a keen hunter[4]

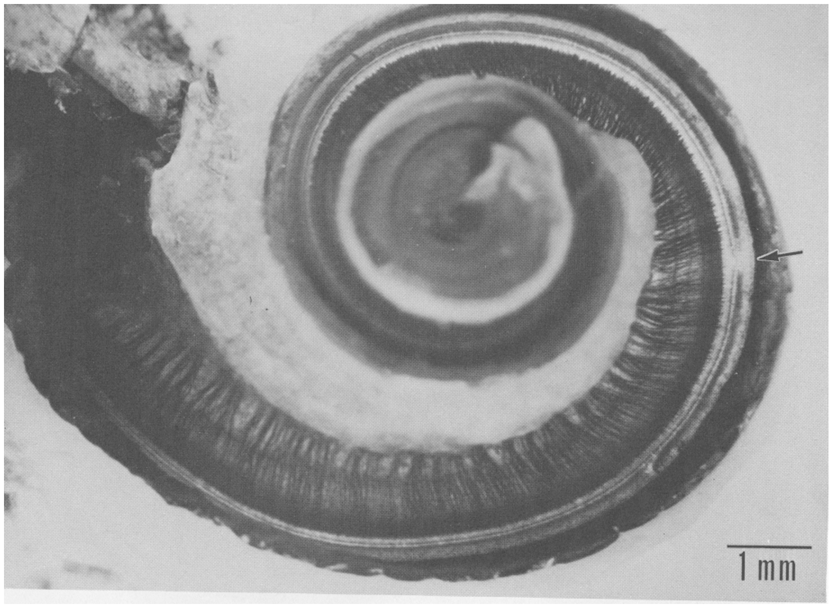

Figure 6 - Cochlea cross section, right ear, 72 year-old male, not exposed to industrial noise but a keen hunter[4]

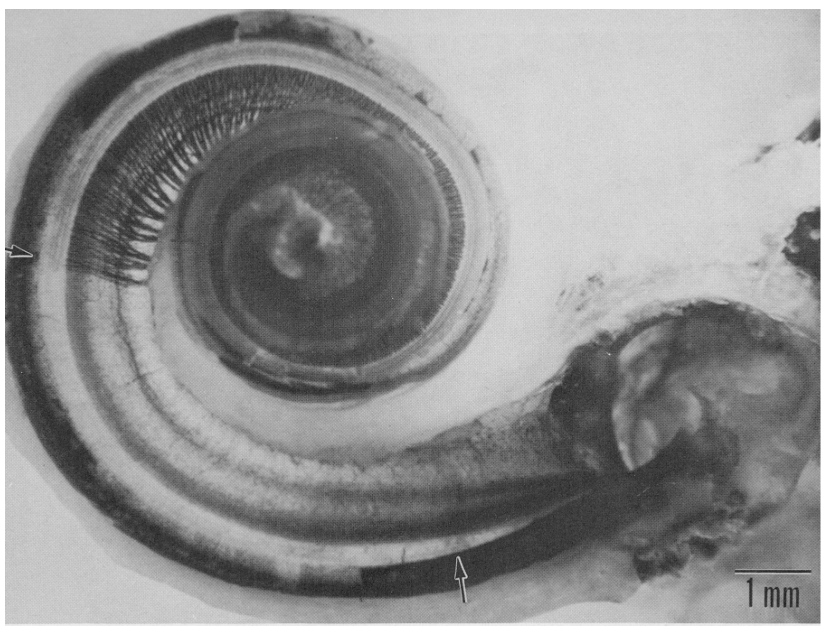

Figure 7 - Cochlea cross section, left ear, 50 year-old male, exposed to industrial noise and a keen hunter[4]

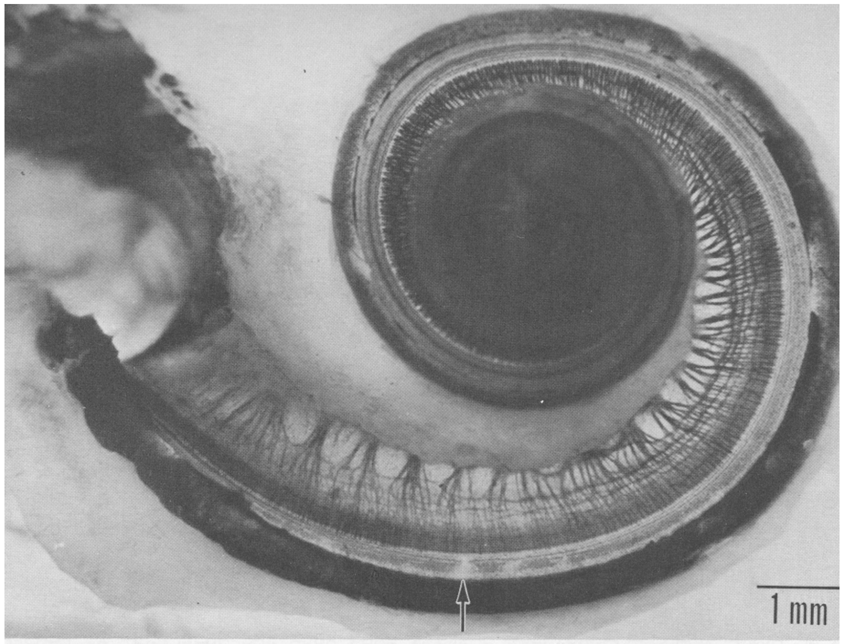

Figure 8 - Cochlea cross section, left ear, 92 year-old female, never exposed to any form of excessive occupational or recreational noise[4]

The pictures show that the degeneration of nerve fibres is clear for both males, especially the 50 year old male who had been exposed to industrial noise and high impulsive noise from gunshot. In the case of the 72 year old male, a clear difference can be seen between the left and right ears, owing to the fact that the right ear is protected from shot noise when shooting a rifle right-handed.

Comparing the cochlea for the young male and the elderly female, it can be seen that there is not a great difference at the high frequencies in terms of the nerve fibres; however the organ of corti in the young male cochlea is more damaged. Clearly the occupational and recreational noise exposure for the young male has affected his high frequency hearing. For the old female, degeneration seems more uniform and can be attributed to Presbycusis. The difference shows that the noise damage caused by the occupational and recreational noise exposure for the young male may have caused this person's hearing to be comparable to that of a 92 year old female.

Philip Wash MSc Environmental and Architectural Acoustics

Noise damage to the ear has been extensively documented over the last fifty years, leading to the development in the UK of The Noise At Work Regulations, which aims to reduce the exposure of noise in the workplace to safe levels. However, even if modern health and safety regulations are successful in reducing or even preventing excessive noise exposure in the workplace, noise exposure through recreation will always be dependent on personal choice and at the control of the individual.

5.0 DEVELOPMENT OF THE MP3 PLAYER

In 1979 Sony released the 'Walkman'; a personal cassette player which was as portable as a small transistor radio. Throughout the 1980's, personal stereos were one of the biggest selling items of electronic equipment, with Sony alone selling an estimated 50 million units between 1979 and 1989[5]. The popularity of 'music on the move' subsequently evolved with the development of the personal compact disc player, the mini disc player and now the Mp3 player.

Ever since the arrival of the Sony's 'Walkman', articles have been written in audiology journals speculating the possible damage caused by over exposure to music which is being produced in such close proximity to the ear. However, as discussed previously, hearing damage is generally caused by exposure over time rather than a single event (unless the event is an extremely high level). One of the main factors affecting the use of personal cassette and compact disc players was the lack of media available and the battery life, both controlling factors of the listening time. In the case of the personal cassette player for example, the ability to play just one cassette meant that the user would rarely carry more than two or three cassettes to listen to (totalling around 30 songs) and the mechanical nature of the device meant that battery life was limited due to the powering of electric motors. Mp3 players however, are low power devices which can store up to 40,000 songs and have a typical battery life of 40 hours[6]. It could be argued, therefore, that due to the massive selection of songs (meaning short attention spans can be catered for) and long battery life, the noise exposure for the average user of a modern Mp3 player could be much longer than that of users of personal cassette players.

As of February 2006, Apple had reportedly sold 42 million 'iPods', often regarded as the industry standard Mp3 player (since its introduction in 2001[7]).

6.0 REPORTED CASES OF HEARING LOSS FROM MP3 PLAYERS

In February 2006 a lawsuit was filed against Apple Inc. by John Kiel Patterson of Louisiana USA. Although it is not medically proven that the accuser suffers from hearing loss, the prosecution lawyer based the case on the claim that the MP3 player is ‘not safe to use as currently sold’ as it does not carry ‘adequate warnings regarding the likelihood of hearing loss’[8]. As far as the author is aware, the case is still pending.

Many arguments have been raised regarding the safety of the noise levels from devices such as the iPod, with the general emphasis placed on whether or not the user has the right to listen to music as loud as they want. In France, for example, government legislation has forced all portable in-ear music devices to be limited to produce levels of no higher than 100 dB(A)[9]. Many independent sources claim that devices such as the iPod are capable of producing levels of 115 dB[8], however whether this is at a particular frequency or an overall Leq is unknown.

Of course, not everyone using an Mp3 player will listen to music at the maximum volume level, however there is always the risk of the volume being increased by accident. To address this problem the latest iPod models produced by Apple contain a user defined noise limiter built into the software, allowing the user to pre-set the maximum volume setting. This means that the user cannot accidentally turn up the volume to the maximum setting.

7.0 PREVIOUS RELATED WORK

7.1 Fligor and Cox

Fligor & Cox, 2004 carried out an extensive study into the noise levels generated by the headphones of commercially available compact disc players. Using a 'dummy head' microphone configuration, white noise was measured through a range of compact disc players and headphones and compared to noise levels of various music samples played in the same arrangement. This enabled the investigators to gain thorough understanding of the different characteristics of a good range of headphones and compact disc players with respect to noise exposure.

7.1.1 Results of the study

The study found that sound pressure levels (free-field equivalent) measured at the maximum volume setting 'ranged from 91 dBA to 121 dBA'[10]. In some headphone/compact disc player combinations, peak sound pressure levels were measured to exceed 130 dB SPL[10]. The experiment also showed that for a given volume control setting, smaller headphones produced higher levels with the 'in-ear' type headphone giving an increase of 7-9 dB.

Figure 9 below shows some of the output levels measured during Fligor and Cox's study[10].

INSERT FIGURE HERE (I have yet to scan this in!!!)

Figure 9

In conclusion, Fligor & Cox noted that, on average, with the volume control set to 70% of the maximum gain, the upper limit of the permissible noise dose as set out by the National Institute for Occupational Safety and Health

(U.S equivalent to UK Noise at Work Regulations) would be exceeded within one hour.

7.2 Serra, Biassoni, Skarp, Serra and Joekes

Serra, Biassoni, Skarp, Serra and Joekes carried out a four year study into the sound emission levels exposed to a group of adolescents form discos and personal music players and the subsequent auditory and psychosocial behavioural effects. The noise levels were measured using noise dose badges (similar to those used in noise at work assessments) fixed to the test subjects whilst they attended their favourite disco venues. In addition to this the test subjects were instructed to regularly report to the laboratory where they would have the levels of their personal stereos measured using a dummy head arrangement similar to that described in Section 6.3.

7.2.1 Results of the study

The investigation found that the test subjects were exposed to levels regularly exceeding 105 dB$L_{Aeq,\ T}$ when frequenting their chosen discothèque[11]. The maximum L_{Aeq} was measured to be 112.4 dB and the minimum 108.4 dB[11]. Levels produced by the subjects' personal stereos were measured to be between 75 and 105 dB$L_{Aeq,\ T}$[11].

The audiogram measurements taken from the test subjects showed that over the four year period, a threshold shift occurred into the third year of measurements. This was considered to be a 'permanent hearing impairment at an early age'[11]. However, it was noted that the use of personal stereos for each test subject was not significant when compared to the high levels produced in discothèques, where the test subjects typically spent 3-4 hours during every visit.

In conclusion, the authors of this study recommended that a limit of 90 dB$L_{Aeq,T}$[11] be applied to music venues such as discotheques, however it was noted that it is difficult to single out a recreational noise source as a sole cause of detrimental noise exposure.

7.3 Deafness Research UK/BMRB - Telephone omnibus survey

In 2006 Deafness Research commissioned BMRB to undertake a survey into recreational noise of the 'iPod generation'. This involved interviewing 1001 people aged between 16 and 50 years, asking questions such as *'time spent listening to TV'*, *'time spent listening to iPod or MP3 player'* and *'frequency of visits to the cinema'.* The aim of this survey was to gauge an understanding of the type of general recreational noise exposure experienced by people in the UK and the regularity of such exposure.

No actual noise measurements were made, however the survey gives an excellent indication into behavioural patterns of people in the UK with respect to recreational noise exposure, especially exposure from personal stereos and Mp3 players.

7.3.1 Results of the study

A large part of the Deafness Research UK study does not have direct relevancy to this investigation, so a full summary would be beyond the scope of this report. However, many interesting points emerged from the survey which were directly related to the use of Mp3 players:

- 13% of Mp3 users aged between 16 and 34 admitted to listening to their Mp3 player for more than 4 hours a day. For people aged between 35 and 49 this figure was much lower at 2%.

- For users with listening periods of less than 1 hour and 1 to 2 hours, the 16-34 age group was fairly evenly split with 34% and 32% respectively saying they listened for these periods every day. Almost all (61%) of the users from the 35-49 age group listened for less than 1 hour per day.

- Over half (51%) of people aged between 16 and 34 said they experienced *'a muffled or buzzing sensation after listening to loud music'* compared to 45% of the 35-49 age group. The highest percentage was in fact the 25-34 age group, with a score of 53%. However, it must be stressed that the source of 'loud music' was not defined.

- When asked to pick from a pre-determined list of the causes of hearing damage, the three most popular choices were *'going to loud bars or nightclubs', 'working in a noisy environment'* and *'working with noisy machinery'*, all with 24% of the vote. *'Listening to Mp3 player, iPod or Walkman'* received only 15%, with most of the votes for this potential cause came from the 16-24 age group. Interestingly, the 16-24 age group named this as the most recognised cause of hearing damage with 44% of the their vote.

In conclusion, it seems that although aware of the potential of hearing damage from listening to an Mp3 player or personal stereo, young people (those aged 16-24) are the most frequent users of such devices.

APPENDIX A

GLOSSARY OF ACOUSTIC TERMINOLOGY