LONDON SOUTH BANK UNIVERSITY

SCHOOL OF ENGINEERING SYSTEMS AND DESIGN

MSc Environmental & Architectural Acoustics

Investigation into MP3 Player Noise Levels and their Effects on Human Hearing

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Abstract

Personal stereos were commercially released during the late 1970's; ever since the release they have continued to be a popular product for consumers.

There has been a rapid increase in the number of MP3 player sales since they're release and with rapid technology development they are continuing to be a success among today's consumers.

Ever since the release of personal stereo's there has been concern regarding noise levels emitted via the headphones in relation to hearing and its effects. It has been stated that a high percentage of consumer's who use portable music devices are unaware of the dangers of listening to audio at high levels whilst using headphones.

This dissertation looks at the effects personal stereos has on human hearing. A number of subjects were tested in terms of the volume they listened to various types of music. Each subject listened to a portion of each track under different circumstances. The circumstances included listening to the tracks in the presence of no background noise and finally in the presence of London Underground train noise.

Acknowledgements

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Contents

1.0 - Introduction

Hearing is one of the five human senses which refer to our ability to detect sound by detecting sound which are in turn turned to vibrations then to electrical impulses. The human ear is an important organ in which there has been a lot of information regarding methods to prevent hearing damage; weather it's from personal use of audio equipment or under government legislation related to work at noise.

The personal stereo is a term given to a portable audio player which allows the user to listen to music through headphones. The first personal stereo was the 'Stereobelt' which was invented and patented by Andreas Pavel in 1977. Pavel attempted to commercialise this product, but failed to do so successfully[1].

It was two years later when the original Sony Walkman was marketed in 1979 in Japan. Sony continued to develop the walkman, releasing various models over the years. In 1984 Sony released the first CD based Walkman, officially called the ‘Discman’. The Discman was a popular product, which was well received worldwide. However the ‘Minidisc’ wasn’t as popular as expected and suffered from poor sales globally[2].

Since the ‘Minidisc’ other products were released that have been extremely popular. Nowadays as technology has improved and is still being improved and marketed at such a fast rate it is difficult to keep up to date with the latest technology in terms of portable music devices. Currently music is now stored on devices such as the common Apple Ipod which is a portable digital music device.

Gone are the days when cassettes, CD’s and minidisc’s have to be carried around for users to enable them to listen to various albums. Digital music is the way how music is purchased and stored for millions of users around the world. MP3 players allow music to be stored digitally on internal memory ranging from 32MB to 80GB. Looking at the latter figure of 80GB, it has been stated that around twenty thousand songs can be stored on devices providing this much capacity.

MP3 players are an extremely popular choice for millions of people around the world in terms of a device that has the ability to stores thousands of songs. With the ever increasing demand of MP3 players it is also a very affordable product.

Reports have suggested that well in excess of one hundred million Ipods have been sold[3]. Adding this figure up with various other MP3 players on the market it is difficult to quantify the total number of portable music devices sold worldwide. Looking at the current rate of improvements in technology and the products affordability factors it’s likely that the sales of portable music players such as the Ipod are still likely to increase over the years to come.

Millions of people who use this rapidly increasing device are unaware of a serious factor which can lead to permanent problems during their life. A serious issue has been overlooked ever since the first portable music device was released commercially.

Hearing loss is the key concern and with regular use at high levels the damage may be irreversible. The risk is also further heightened when using headphones in noisy environments, such as a factory, public transport or on busy streets. When using headphones in such environments, users automatically increase the volume in order to block out the background noise that is surrounding them.

The key issue since the commercial release of personal stereos is hearing damage. It has been found that a high percentage of people who use MP3 players have little or no idea of the effects of listening to audio at high levels via headphones.
Detailed literature regarding hearing impairment via the use of headphones is fairly limited. It has been noted that there is literature on effects caused by prolonged headphone use; but a certain proportion of this is repetitive and isn't as detailed as needed.

2.0 - Literature review

2.1 - Fundamentals of Sound

Sound is known as vibrational transmission of mechanical energy that propagates as a wave. Sound needs a medium before it can be propagated, and the medium can be any elastic material such as air, water, wood, plastic and many other materials.

Sound is produced when the air is disturbed in some way, for example by vibrating an object. When sound is produced, humans in turn can hear these sounds through their sense of hearing[4].

The speed of sound varies depending on the medium which the waves are passing through. Speed of sound through air is measured at around 344 m/s. The speed increases as the medium it is passing through becomes denser.

2.2 - The Ear and the Perception of Sound

The human ear is an extremely important organ, not only does it act as a receiver for sound, but also plays an important role in the sense of balance and body position.

The ear has incredible sensitivity which equates to responding to minute pressure variations in the air. Our ears have an average audible range from 20 Hz to 20 KHz; however this will vary for each individual. The threshold of hearing is 0 decibels, while the threshold of pain is 140 decibels.

Human frequency range changes accordingly to each individual as their age increases. Healthy newly born babies and young children are likely to have the full frequency hearing range. However as we become older the frequency range is reduced, especially at the upper limit of the range. From the age of 20, the upper limit may have dropped to 16,000 Hz. The frequency range continues to decay gradually to around 8,000 Hz by the age of sixty five. This common process is known as presbycusis[5].

Figure 1 shows the auditory area of human hearing. Curves A and B were obtained from groups of trained listeners[5]. The audibility area as shown below was found by listeners facing a sound source and judging whether a tone of a certain frequency is barely audible (curve A) or beginning to be painful (curve B)[5]. The curves shown below give an accurate representation of the extreme limits of human's perception to loudness.

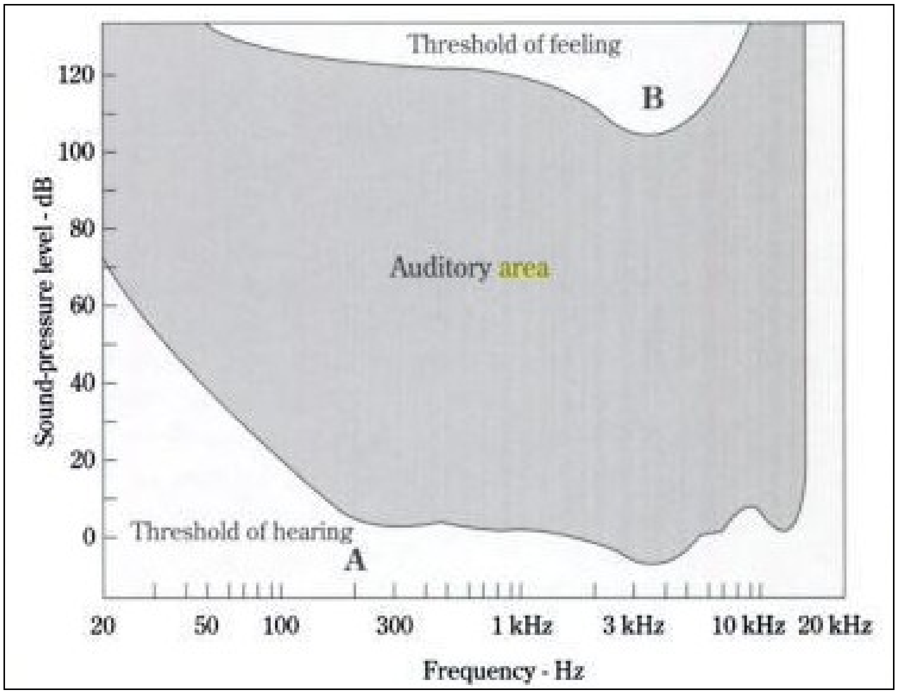

Figure 1 - Auditory area of human hearing[5]

Figure 2 shows the anatomy of the human ear. It is often split into five common sections, so the understanding of how the ear works is easily understood.

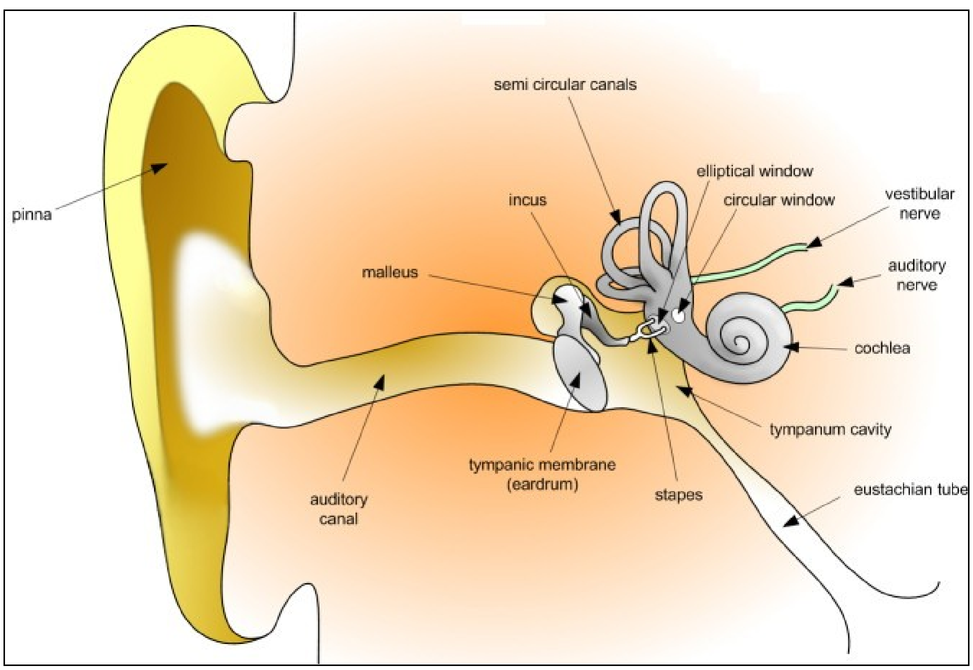

Figure 2 - Diagram of the human ear[6]

The auditory system comprises the ear and their connections to and within the central nervous system. In order to understand the ear and how it works it is common to divide the ear into the following categories[7]:

- Outer ear
- Middle ear
- Inner ear
- Acoustic nerve
- Brains auditory processing centres

2.2.1 - Outer Ear

The outer ear consists of auricle and external auditory meatus. The auricle is irregularly shaped and of a variable size, it also consists of many groves, ridges and depressions. The final part of the outer ear is the ear canal, which is approximately 25 to 35 mm long and this extends to the tympanic membrane.
The outer ear has an acoustic effect on sounds as they enter the ear, as it helps us locate sound sources around us and also enhances some frequencies with respect to others.

Sound localisation is helped mainly by the acoustic effect of the pinna and ear canal. The combined effect of these two particular parts of the outer ear are extremely useful for determining whether a sound source is in front or behind the person and to a lesser extent whether it is above or below us[7].

2.2.2 - Middle Ear

The middle ear, an air filled cavity behind the tympanic membrane includes the three ossicles; the malleus, incus and the stapes.

The tympanic membrane is a thin membrane which separates the external ear from the middle ear. Its primary function is to transmit sound from the air to the three ossicles which are located inside the middle ear. Each of the three ossicles serves as an integral part of the functioning of the ear. The malleus bone bridges the gap between the eardrum and the remaining ossicles.

The malleus is attached to the eardrum and the stapes is attached to the oval window of the inner ear. The ossicles create a mechanical lever action connection between the air filled middle ear and the fluid filled cochlea within the inner ear. The middle ear also has an opening to the upper throat behind the nasal passage; this is known as the Eustachian tube. The Eustachian tube has a function of equalising the air pressure of the middle ear with the atmospheric pressure around us. This enable the eardrum and the delicate membranes contained within the ear to function properly. The Eustachian tube opens when we swallow and this equalises air pressure within the middle ear.

Figure 3 shows the eardrum along with the three ossicles and the opening of the Eustachian tube.

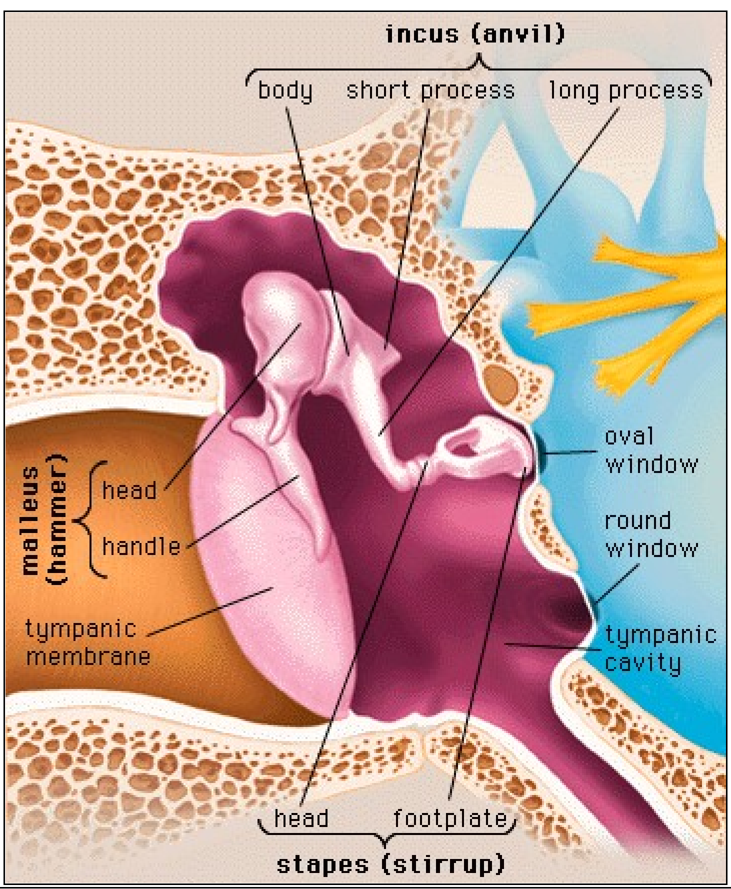

Figure 3 - The human ear drum and three ossicles[8]

The eardrum is set into vibration by any incoming pressure waves; the vibrations occur at the same frequency as the pressure waves. The frequency is transmitted through the middle and inner ear and provides the perception of pitch. Thus, higher frequency vibrations are perceived as higher pitch sounds and lower frequency vibrations are perceived as lower pitch sounds[7].

The ear drum can rupture from infection, trauma, an explosion or from loud noise. If this does occur, it tends to lead to conductive hearing loss. If a perforation does occur, healing can range from a few weeks or up to a couple of months. Unless a serious matter has occurred; hearing is generally recoverable; there are cases when hearing damage is irreversible which will lead to permanent hearing damage[4].

Figure 4 shows the difference between a healthy and a ruptured eardrum.

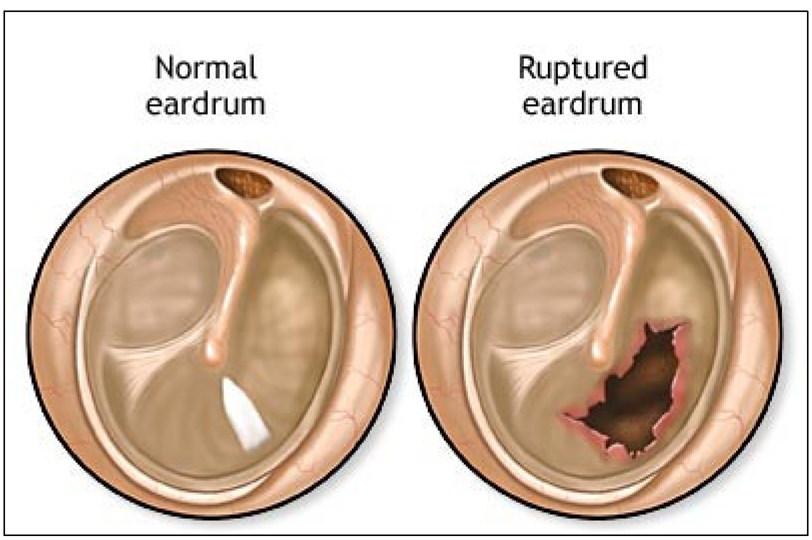

Figure 4 - Difference between a healthy and a ruptured eardrum[9]

2.2.3 - Inner Ear

As sound enters the ear, the pinna directs the sound into the middle ear. The middle ear allows the pressure waves to be translated into mechanical vibrations. The cochlea of the inner ear propagates the mechanical signals as waves in fluid and membranes, this finally transduces the waves to nerve impulses which are then transmitted to the brain.

- **Cochlea**

Figures 5 and 6 show the difference between a healthy and damaged cochlea. As it can be seen there is a vast difference between the two. These images show the results of being exposed to high noise levels for long periods of time.

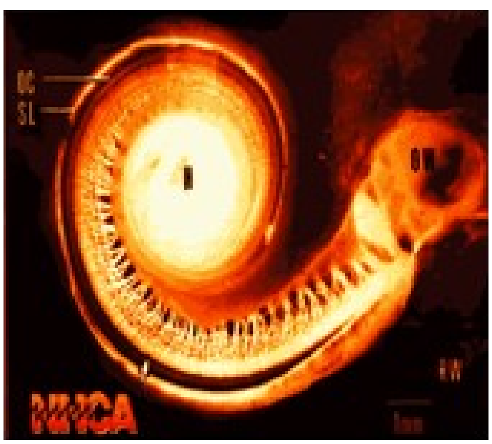

Figure 5 - Healthy cochlea[10]

Figure 6 - Damaged cochlea[10]

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Corti

This particular organ is key to the hearing system and contains the auditory sensory cells, more commonly known as hair cells. It is an extremely specialised organ that responds to fluid borne vibrations in the cochlea. It contains between 15,000 to 20,000 auditory nerve receptors in which each receptor contains its own hair cell[7].

The following images show the varying types of damage to the sensory cells of the cochlea caused by noise exposure, resulting in hearing loss[11]. Figure 7 shows the sensory surface of a normal organ of corti. Three rows of outer hair cells and one row of inner hair cells.

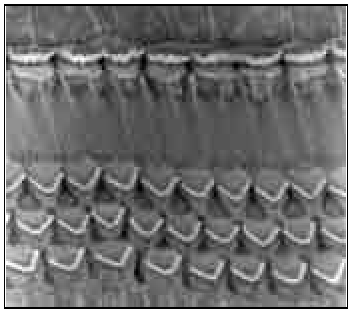

Figure 7 – Healthy organ of corti[11]

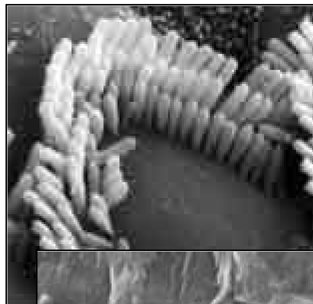

Figure 8 – Mildly damaged outer hair cell [11]

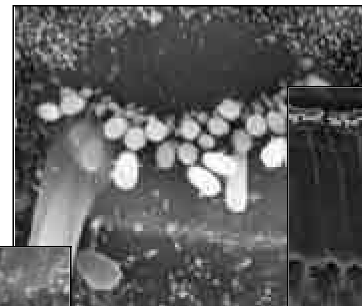

Figure 9 – Mildly damaged inner hair cell[11]

Figure 10 – Severely damaged outer hair cells [11]

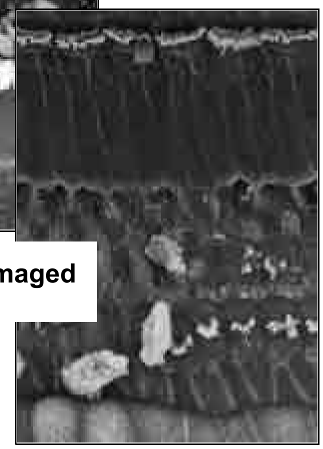

Figure 11 – Severely damaged organ of corti[11]

Figure 8 shows a mildly damaged outer hair cell. The stereocillia are disarrayed, the linkages between them are partially damaged impairing the function of the cell. Figure 9 shows a mildly damaged inner hair cell. The stereocillia are slightly disordered and several of them have fused together to form a large 'stereocillium'[11].

Figure 10 shows severely damaged outer hair cells. To the left a missing hair cell has been replaced by in growing supporting cells. To the right there are two hair cells that have merged together; it is highly improbable that these cells serve any active function. Figure 11 shows a severely damaged organ of corti. The first row of outer hair cells is most susceptible to any type of damage, the second and third row of outer hair cells show decreasing degrees of susceptibility[11].

2.2.4 - Acoustic Nerve

The acoustic nerve carries impulses from the cochlea to the cochlear nucleus in the mid brain and then onto other brain pathways that end in the auditory cortex of the brain.

At the cochlear nucleus, nerve fibres from each ear divide into two pathways. One pathway ascends straight to the auditory cortex on one side of the brain and the other pathway crosses over and ascends to the auditory cortex on the other side of the brain. As a result, each side of the brain receives information from both ears[7].

2.2.5 – The Brain's Auditory Processing Centres

The final section of the auditory system is the brains auditory centres; this deals with the processing of auditory information as it is carried up to the brain. The central auditory processes are responsible for the following behaviours[7]:

- Sound localisation and lateralisation
- Auditory discrimination; this is hearing the differences between different sounds
- Recognising patterns of sounds
- Time aspects of hearing (temporal masking)
- Reduction of auditory performance in the presence of competing acoustic signals
- Reduction of auditory performance in the presence of degraded acoustic signals

2.3 – Hearing Loss

2.3.1- Noise Induced Hearing Loss

Noise induced hearing loss (NIHL) is a disorder that results from exposure to high frequency sounds. Noise induced hearing loss can be divided into two types[12]; gradual and increasing loss of hearing and the more extreme type known as acoustic trauma.

When high levels of sound intensity is transmitted into the auditory system it causes noise induced hearing loss. When sound enters the human hearing system, the sound is eventually transmitted through the eardrum. The eardrum acts as a diaphragm and sets the system of the middle ear into motion. The ossicles within the ear transfer mechanical energy to the cochlea by way of the stapes hitting the oval window[12]. The fluid within the cochlea is pushed against the stereocilia of the hair cells which transmit a signal to the central auditory system in the brain. When excessive sound is heard by the ear the force on the stereocilia of the hair cells becomes damaged and this produces abnormalities to the cells.

Gradual and increasing loss of hearing is a problem which is caused by repeated exposure to loud noise, such as train noise, busy streets and offices or listening to MP3 players on a regular basis. It may not be obvious at the time, but we are surrounded by various noises that emit high noise levels which over time could cause hearing damage.

Initially, when exposed to loud noise for a certain period of time it is common to cause temporary hearing loss, more commonly known as temporary threshold shift. When temporary threshold shift occurs, a period of at least 24 hours should be observed in order to give the ears a rest and also in order to return to their normal state. If loud exposure is continued or inadequate time is given for the ears to rest, this usually results in permanent threshold shift[13]. When this occurs, the hearing loss becomes permanent and irreversible.

It can be said that over stimulation of the hair cells by excessive noise weather it is a high intensity noise such as an explosion or gradual noise over a period of time can cause noise induced hair loss.

2.3.2 - Prevention of Noise Induced Hearing Loss

NIHL can be prevented by various methods that are readily available and affordable. If a subject is employed and working in an environment with levels from 80 dB then the employer should at least provide some sort of hearing protection.

Methods of prevention include hearing protection; there are a wide range of hearing protection products on the market. Hearing protection can provide between five to ten decibels of attenuation. Education and hearing conservation programmes can allow information regarding hearing protection.

2.3.3 - Conductive Hearing Loss

This is caused by anything that interferes with the transmission of sound from the outer ear to the inner ear. Some of the causes of conductive hearing loss include the following[14]:

- Middle ear infections
- Collection of fluid in the middle ear
- Blockage of the outer ear, most commonly caused by ear wax
- Otosclerosis, a condition in which the ossicles of the middle ear harden and become less mobile
- Damage to the ossicles, may be caused by a serious infection or head injury

- Perforated ear drum, which can be caused by an untreated ear infection, head injury, blow to the ear or poking something into the ear

2.3.4 – Sensorineural Hearing Loss

The cause of sensorineural hearing loss lies within vestibulocochlear nerve, the inner ear or the central processing areas of the brain. This particular hearing loss can be placed in any of the following categories[14]:

- Mild
- Moderate
- Severe
- Total deafness

When this particular type of hearing loss occurs it is usually caused by abnormalities in the hair cells within the cochlea. When the functioning of hair cells is poor it can be due to problems at birth or damage caused to the individual during their lifetime. Some of the causes include the following[14]:

- Age related hearing loss (Presbycusis, due to loss of hair cells in the cochlea
- Acoustic trauma can damage hair cells
- Viral or bacterial infections can lead to loss of hair cells or damage to the auditory nerve; such as mumps and meningitis
- Meniere’s disease, which causes dizziness, tinnitus and hearing loss

- Certain drugs can cause permanent hearing loss. At high doses, it is thought that aspirin can cause temporary tinnitus. Also, antimalarial drug quinine can cause temporary tinnitus
- Acoustic neuroma, this is a tumour affecting the auditory nerve; it needs to be observed and is sometimes treated with surgery

Currently sensory hearing loss can be treated with hearing aids which amplify sounds at pre set frequencies to overcome hearing loss at that particular range. Another method is a cochlear implant, which can stimulate the cochlear nerve directly.

2.3.5 - Temporary Threshold Shift

This occurs when a person has been exposed to noise levels of 80 dB and above for a few hours. This often leaves ringing in the ears for some time afterwards. The greater part of the hearing loss occurs soon after exposure and recovery usually occurs within 30 minutes when removed from the high noise levels. Persons exposed to continuous noise at a level of 100 dB(A) for an 8 hour working day could show a temporary threshold shift up to 40 dB in that part of the spectrum most affected[13]. Such a shift may be caused by other means such as use of aspirin or other drugs.

2.3.6 - Significant Threshold Shift

A shift in hearing threshold outside the range of audiometric testing variability (5 dB), that warrants follow-up action to prevent further hearing loss. The National Institute for Occupational Safety and Health defines significant threshold shift as an increase in the hearing threshold level of 15 dB or more at any frequency (500, 1000, 2000, 3000, 4000, or 6000 Hz) in either ear that is confirmed for the same ear and frequency by a second test within 30 days of the first test[13].

2.3.7 - Permanent Threshold Shift

Permanent shift occurs when the ear is subjected to high intensity noise on a regular basis, such as day after day; this effectively causing more lasting damage[5]. This occurs when a person may not recover fully between exposures and what started as a temporary threshold shift eventually becomes permanent hearing damage.

2.4 - Audiogram

Figure 12 shows the results of a subject's audiogram. This shows the differences between normal hearing and profound hearing loss[15]. There are certain differences when a person suffers from the different levels of hearing loss; they include:

- Normal hearing
  - This occurs when all the results are above the 20 dB line, usually common in the younger generation[15].
- Mild hearing loss
  - Sound below the line can be heard, hearing not severely affected[15].
- Moderate hearing loss
  - Sounds below the lines on the audiogram can be heard. Low/loud sounds like oo, ah, ay and ee may be heard[15].
- Severe hearing loss
  - Conversational speech cannot be heard. Shouting and loud noise (like traffic) can be heard[15].
- Profound hearing loss
  - Speech cannot be heard. Very loud noises like pneumatic drills and planes taking off can be heard (or felt). People with very profound hearing losses can feel loud low sounds[15].

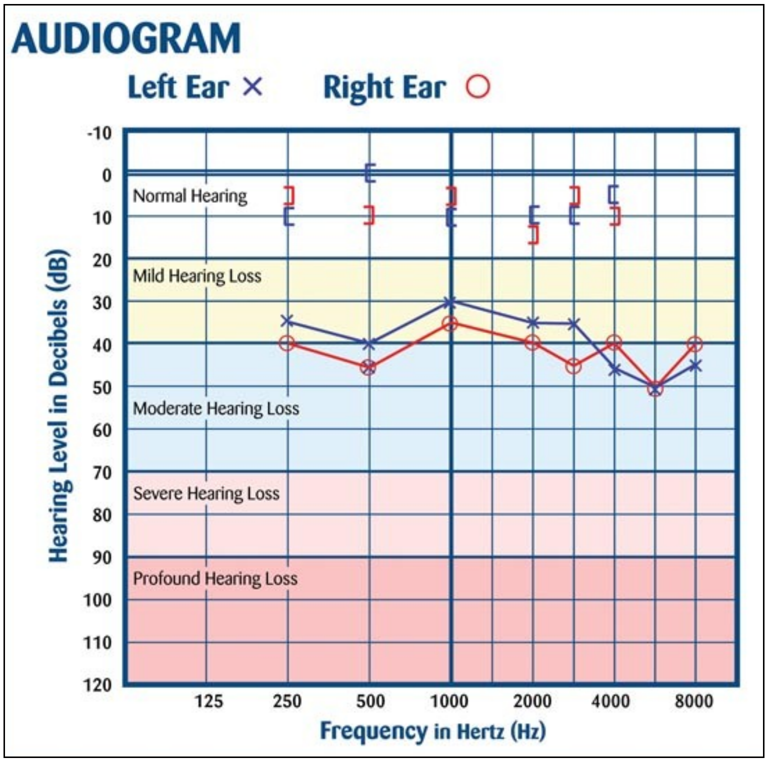

Figure 12 – Example of an audiogram[16]

Figure 12 shows the differences in levels between normal hearing and profound hearing loss. Looking at this chart it shows what experts are predicting with the current 'Ipod generation'. Experts are currently stating that regular headphone users are expecting to suffer from severe and profound hearing loss at a much earlier age.

2.5 - Noise Level Comparisons

Various reports state that levels on various MP3 players can reach 120 dB; this is as loud as an emergency vehicle siren. Looking at various noise levels in table 1 it puts the noise levels of MP3 players into prospective. Threshold of pain is 140 dB and comparing this level with the level of some MP3 players on maximum volume is quite worrying.

Activity	Level (dB)
Threshold of pain	140
MP3 player on 'Max'	120
Jet aircraft	120
MP3 player on 'loud'	112
Propeller aircraft taking off	110
Pneumatic drill	100
Noisy pub	90
Busy workplace	80
Busy street	70
Busy shop	60
Normal conversation	50
Average noise level at home	40
Quiet conversation	30
Whisper	20
Rustling of leaves	10
Threshold of hearing	0

Table 1 - Comparisons between typical noise sources[5]

The Royal National Institute for Deaf People (RNID) report that two thirds of young people who regularly use MP3 players face premature hearing damage due to listening to their MP3 players too loud[17].

Amongst this particular finding, the institute also commented that over eight million MP3 players were sold last year in the UK alone. The RNID have accused manufacturers of failing to advise clear warnings on the packaging regarding hearing damage with excessive noise levels of MP3 use[18].

The RNID has suggested that MP3 player users should invest in in-ear filters for their headphones; this will cancel out background noise and hopefully prevent users from increasing the volume.

It has also been stated that 72 out of 110 MP3 users tested in Birmingham, Brighton and Manchester were listening to their MP3 players at volumes higher then 85 dB. It has been stated in the World Health Organisation (WHO) that listening to levels of above 85 dB for more than an hour at a time can cause hearing damage[19].

Brian Lamb, acting chief executive has stated that 'If people can hear the music from your headphones from just a meter away, you're putting your hearing at risk'[17].

From the subjects tested, RNID also found that almost half of young people who use MP3 players listen for more than an hour a day; with a quarter listening for more than 21 hours a week. 58% of those surveyed by the RNID were unaware of the risk they were causing to their ears and 79% of those subjects had never seen warning's on the packaging of their MP3 players[17].

A study carried out in July 2006 by Deafness Research UK and Specsavers Earcare has found results to a survey quite alarming[22]. They're results showed that young people today are likely to lose their hearing thirty years earlier then the previous generation due to the rise in personal stereo use.

The survey of one thousand people found that 14% of people spend up to twenty eight hours a week listening to their MP3 players and that a third of people who have had ringing in their ears still listen to their MP3 players everyday.

A common result found from various studies related to personal stereo use and hearing is that a certain percentage of users don't realise that they can damage their hearing from using personal stereos at high volume levels.

2.6 - MP3 Player and Noise Levels Research

2.6.1 - RNID MP3 Players and Personal Stereo use Research

RNID carried out research regarding hearing loss and the use of MP3 players and personal stereo use. The research was carried out over a 12 day period and found the following results[20].

- 66% of young people (18 to 30) go clubbing at least once a month. Amongst that 18 to 24 year olds this figure is 82%

- 73% of people who have ever been to a club, gig, concert or festival have had ringing in their ears after a night out or the morning after
- 66% of those surveyed said they regularly experienced ringing in their ears
- 64% considered that losing their hearing would have a huge impact on their lives
- 46% interviewed knew that ringing in the ears is a warning sign of damage
- 59% didn't realise that the damage would be permanent
- 27% of people interviewed said they knew how to look after their hearing
- 80% of those interviewed knew about the risk of their hearing through volume, but only half knew that the length of time of exposure also affects the likely damage to hearing

2.6.2 - Frequency Range of Speech and Music

The frequency range of music and speech vary accordingly to the human ear. Speech ranges from 170 Hz to 4,000 Hz; it has a dynamic range of 42 dB and covers around four and half octaves. Looking at figure 5 it shows that speech is placed in the middle of the auditory graph. The frequency of speech being placed in the middle makes sense because speech does not contain extremely soft or loud sounds nor does it contain extremely low frequency or high frequency sounds.

Figure 13 shows a graph related to the average frequency range of speech.

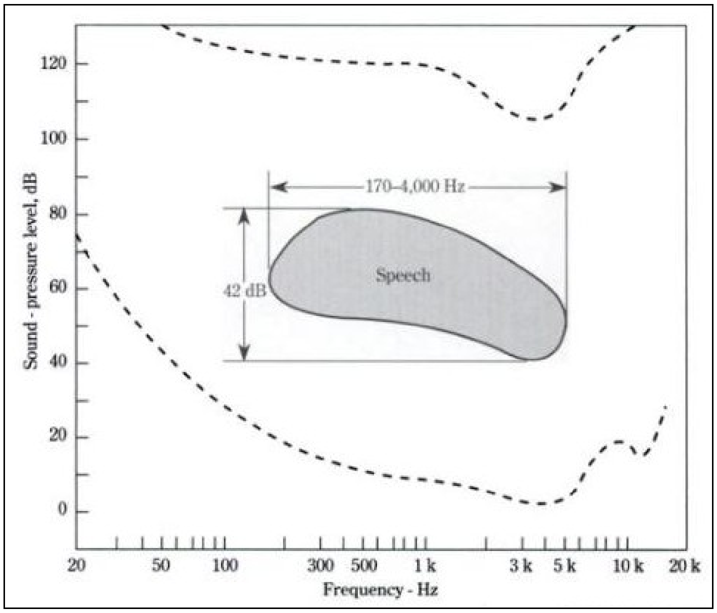

Figure 13 - Typical frequency spectrum of speech[5]

Figure 14 shows the frequency range of music, immediately it is obvious that the frequency range is much larger when compared the speech frequency range. Music uses a much greater proportion of the auditory system. The dynamic range for music is around 75 dB. Its frequency ranges from 50 Hz to 8.5 KHz and has a frequency span of around seven and a half octaves[5]. This is a fairly high frequency span seeing as the human ear has a span of ten octaves.

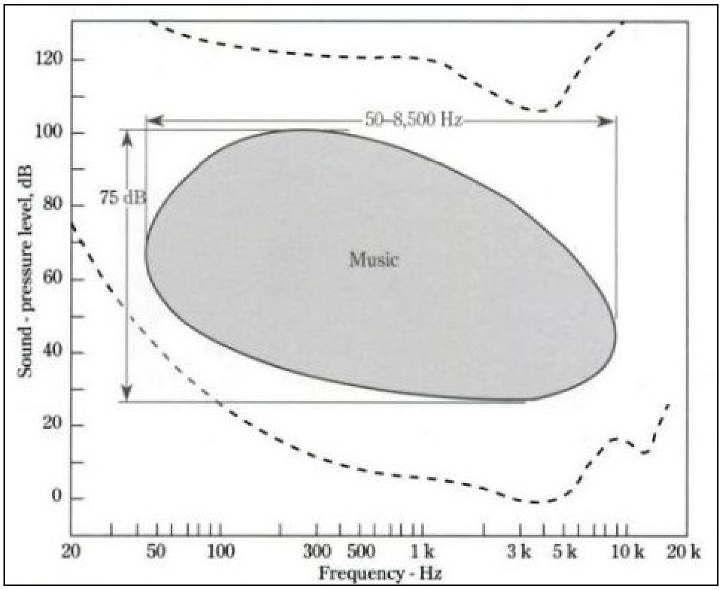

Figure 14 - Typical frequency spectrum of music[5]

2.7 - Noise Levels on the London Underground

It is common for many MP3 player users to increase the volume to reduce background noise around them. A study was carried out in November 2007 by the UK Noise Association into announcements on the London Underground system, both in the trains and on the platforms[23].

Common noise sources within the London underground include announcements regarding train delays, general information, personal safety and arrivals. Other sources include communication amongst commuters, noise from distant and approaching trains and buskers. As with many stations on the London Underground, reverberation plays an important role. Many walls on the platforms are fitted with ceramic tiles; tiles are hard surfaces and easily allow sound waves to reflect of walls until the sound disappears.

With so many noise sources surrounding commuters on the London Underground, it is easy to see why many commuters using personal stereo's increase the volume to reduce the ambient noise around them.

The London underground is not the only problem however. Many streets and towns have high background noise levels. The following report shows the noisiest trains and platforms within the London Underground.

Table 2 shows the noisiest trains on the London Underground, comments have also been included regarding the findings when the research was carried out. It must be noted that 'C' weighted measurements were used throughout the surveys for the London Underground surveys; this is because this particular weighting is better at capturing low frequency noises.

London Underground Line	Comments
Piccadilly line	Nominated by everyone interviewed. The announcements on the trains regularly exceed the noise of a jet landing at London Heathrow.
Northern line	Systems are either cheap or badly installed. Announcements on trains can reverberate around carriages.
Central line	Announcements not as loud as the first two stations, but need to be audible over the background noise present on these particularly noisy trains.
Victoria line	Results vary, at times, announcement can be barely audible and other times it can be excessively loud.
District line	Announcements made on a regular basis on refurbished trains, although levels can be fairly loud.
Jubilee line	Announcement levels can be intrusive when the train is not in a tunnel; otherwise they are adequate in terms of noise levels.
Bakerloo line	Levels seems much more acceptable, not too loud and not to quiet.

Table 2 - Comments by commuters regarding noise levels on the London Underground[23]

The noisiest station found was Bank. The volume of the announcements was clearly louder then expected. It must be noted that only about a third of the stations on the London Underground were tested. The levels for Bank are shown in table 3.

Station & Line	Background noise level on platform, dB (C)	Noise level with platform announcements, dB (C)
Bank, Northern line	83-86	99
Bank, Central line	83-87	101

Table 3 - Background platform and announcements levels[23]

Table 4 shows background levels, noise levels as trains approached the platforms and the noise levels of the announcements on the platforms. Table 4 shows these levels at various stations on the Underground network. It gives a good indication of the current levels and shows that levels need to be reduced for hearing comfort.

Station & line	Background noise level on platform, dB (C)	Noise level as train approached, dB (C)	Noise level with platform announcements, dB (C)
Stockwell, Northern line	57-85	87-98	81-89
Notting Hill Gate, Central Line	65-84	High 80's – Low 90's	82-89
Baker St, Metropolitan line	71-77	85-87	Results did not register, much higher then background level
Baker St, Bakerloo line	66-88	87-95	-
London Bridge, Jubilee line	70-77	97	80-83

Table 4 - Noise levels from a selection of London Underground stations[23]

2.8 - Noise Cancelling Headphones

2.8.1 - Technology in Acoustic Noise Cancelling Headphones

The key advantage of noise cancelling headphones is that their primary concern is to reduce unwanted ambient noise by the means of active noise control. The primary objective for standard headphones is to deliver audio, they do very little to reduce background noise.

Active noise control is a method of reducing unwanted sound; and it is this particular piece of technology which has been incorporated into the Bose Quiet Comfort headphones.

This particular technology works by using a microphone which is placed within the headphone casing. The circuitry involved generates anti-noise sound waves with the opposite polarity of the sound wave arriving at the microphone. This results in destructive interference when two sound waves in the same phase collide with each other[24]. This effectively cancels out the noise within the enclosed area of the headphone. The background noise is not completely cancelled out, but is very noticeably reduced.

The idea of noise cancellation headphones is for the user to enjoy audio without turning the volume up to dangerous levels. They can also be used in other ways, such as to sleep during a flight.

Noise cancellation headphones generally cancel out low frequency noise, which in many cases background noise is within the lower end of the frequency spectrum. In order to reduce higher frequencies the circuitry would have to be re-designed which would be highly complex. Also active cancellation becomes much more difficult at higher frequencies because the wavelengths are much shorter to those of lower frequencies. In order to reduce higher frequency components the sensor and emitter for cancelling waveforms would have to be adjacent to the ear drum, this has been classed as an impractical solution.

Noise cancelling headphones come in either active or passive types; although any type of headphone can provide passive reduction. This is because the materials used for headphones do block some of the sound waves out.

The best type of passive noise reduction headphones are circum-aural types, as they are constructed to maximise noise filtering properties, they are constructed with high density foam or other sound absorbing material, making the headphones heavier. It has been stated that the extra weight of these headphones can provide a reduction in noise of around 15-20 dB. As this is adequate in certain circumstances it is also limited, so this is why active headphones are more appropriate in other circumstances.

2.8.2 - Inside Noise Cancelling Headphones

Figure 15 shows a basic illustration on how noise cancelling technology works. The wave form representing the ambient noise is the same as the wave being emitted from the headphones. Both waves have the same amplitude and frequency, but the compressions and rarefactions are arranged so that the compression of one wave lines up with the rarefaction of the other wave and vice versa. This is what causes two waves to cancel each other out, also known as destructive interference; this means the listener can enjoy the music and is not disturbed from the incoming ambient noise.

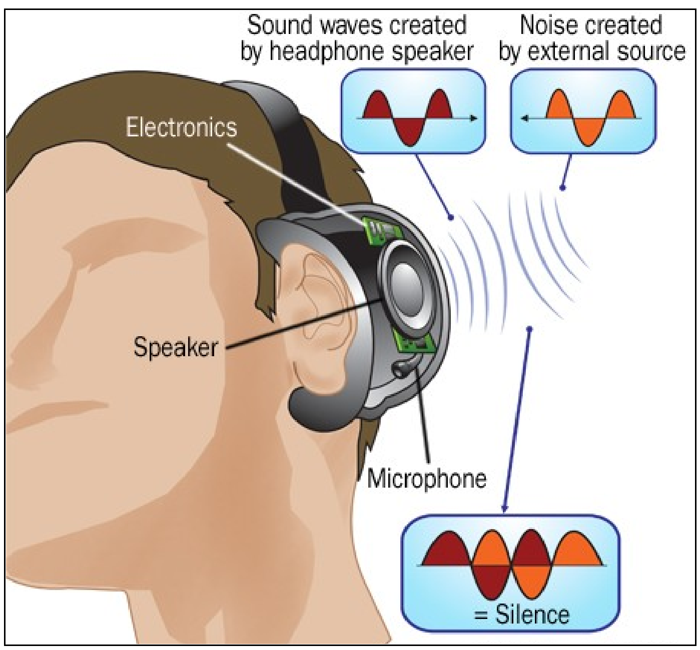

Figure 15 - How noise cancelling headphones operate[26]

In order for active noise cancelling headphones to achieve its full capabilities certain components are required, they include:

- **Microphone**

A microphone placed inside the ear cup that "listens" to the ambient sounds surrounding the user, this is the main difference between active and passive; this cannot be blocked passively.

- **Noise Cancelling Circuitry**

  Electronics fitted within the ear cup sense the input from the microphone and generates a "fingerprint" of the noise, noting the frequency and amplitude of the incoming wave. The electronic circuitry is designed so that it can create a new wave that is 180 degrees out of phase with the waves associated with the noise.

- **Speaker**

  The "anti-sound" created by the noise-cancelling circuitry is fed into the headphone's speakers along with the normal audio; the anti noise erases the noise by destructive interference, but does not affect the desired sound waves in the normal audio.

- **Battery**

  The term "active" refers to the fact that energy must be added to the system to produce the noise-cancelling effect. The source of that energy is a rechargeable battery; battery life is generally of a high standard, lasting for many hours. Early editions of noise cancelling headphones were not fitted with rechargeable batteries; instead standard non rechargeable batteries were used.

2.8.3 - Problems Associated with Noise Cancelling Headphones

A number of problems have been associated with noise cancelling headphones since their release, but as newer models are produced and released commercially the problems are usually improved or eliminated.

Firstly, they use batteries for operation, so there's the need to replace or regularly recharge the battery. Since the release of these particular types of headphones other manufacturers followed suit; thus producing their own interpretation of noise cancelling headphones. Some of the cheaper ones on the market today are very poor and not worth the money[25]; ideally for optimum effect it's worth spending extra money for the well known brands that have been proven to reduce background noise effectively.

Secondly they may not cancel noise effectively; some cheaper headphones may become overloaded by low frequency pressure waves which effectively distort the signal.
Earlier models were bulky and more noticeable then traditional headphones. But as research and development continued later models were reduced in size and were much more practical[25]. Noise cancellation headphones are generally heavier due to the circuitry placed within the headphones.

Lastly, due to its content the headphones may pick up and convert stray electromagnetic fields from time to time.

2.9 - Headphones

2.9.1 - Types of Headphones

Shure, an earphone manufacturer has stated that hearing loss is not related to the type of headphone that is used[26]. Many doctors asked about hearing loss and MP3 use have stated that hearing loss is mainly related to volume levels rather then headphone type.

Headphone types can be split into four different categories. These include:

- Circum-aural

These headphones have circular ear pads that fit around the ears as opposed to on or in the ear. They are generally used in recording studios or audio enthusiasts. As the ear pad fits around the ear it creates a seal; this is useful for blocking out background noise to a certain extent. Depending on the ear pad, it may prevent the user increasing the volume on the headphones to block any background noise present.

Figure 16 – Circum-aural headphones

- Supra-aural

These particular types of headphones have pads that sit on the ear rather then sit around or placed within the ear. These particular types of headphone were common with personal stereos during the 1980's; they are very rarely used in today's market.

Figure 17 – Supra-aural headphones

- Ear bud

These are perhaps the most common and more favoured type of headphone for millions of audio users, due to their inexpensive price tag and ease of use. They are positioned directly outside of the ear canal.

Figure 18 – Ear bud headphones

- In-ear

  These can also be known as canal phones. These are inserted directly into the ear canal. These are used specifically to block out any background noise. The disadvantage with this particular type of headphone is the closeness of the headphone to the ear canal. Using these headphones at high volumes for long periods of time can cause lasting hearing damage.

Figure 19 – In ear headphones

Although many have suggested that it is the volume that is the main concern; it is important to look at the effects of over ear and in ear headphones.

2.9.2 - Dangers of Headphone use

With the majority of people who use headphones, they are unaware of hearing damage in relation to listening to audio via headphones at high volumes. In many cases users generally increase volume levels when high background noise levels are present, many users are turning up the volume to completely block out any background noise present.

Many manufactures have attempted to introduce ‘limiters’ on their products in order to have the volume to an acceptable level and also bearing in mind the main issue of hearing damage. Although it is encouraging to see manufacturers trying to curb the problem associated with hearing impairment and headphone use, many consumers don’t believe that the manufacturer is in the right. Many consumers have stated that they themselves should decide on what level their personal stereos should operate at. One manufacturer introduced the ‘Safelite’ this was introduced on portable cassette players in 1983, it came with a warning light for when levels were too high and posed a threat[27]. Although the idea was feasible and advantageous with its warning light it was discontinued two years later due to lack of interest.

The French government has imposed a limit on all music players that are sold in the country. Limit imposed must ensure that all music players must not be capable of producing 100 dB(A). Many users believe this is an infringement on personal use. Many users tend to download specialist software that reverses the limit placed on devices, allowing levels to exceed 100 dB(A).

When comparing personal stereos that were released in the 1980's with the MP3 players today, there are some major differences on why hearing damage today is a much more major threat then in the 1980's.

2.10 - Personal Stereo Players and their Effects

2.10.1 - MP3 use and Hearing

Brian Fligor an Audiologist specifically interested in personal stereo use and hearing loss has found some interesting results during his research. It has been stated that the thing that damages your ears is prolonged exposure to excessive volume levels[28].

How loud music is listened to on MP3 players and the duration the subject listens for are two important factors that Brian Fligor states could help provide safe listening guidelines for the future.

The research conducted consisted of testing one hundred subjects and looking at how loud the subjects listened to their MP3 players in different background noise environments.

Analysis of the results show that no matter what type of headphones are used, weather they are in-ear headphones or over-ear headphones; 6% of subjects still listened to music at loud levels when the background noise was quiet. 80% of participants listened to music at loud levels when the environmental background noise was loud[28].

From this particular study it was found that it doesn't matter which type of headphone the subject is using, it's the background noise which makes people listen to music at high volumes.

2.10.2 - Expert Advice

From the research conducted a lot of the literature has mentioned several options in order to prevent hearing loss from the use of MP3 players. It should also be noted that current research into this particular area is limited meaning many journals and literature has been quoted of papers of the same literature. Recently, Pete Townsend, guitarist of The Who has given a warning regarding hearing loss to this generation of Ipod users. At the age of 60 he has stated that years of using studio headphones has caused severe hearing loss[29].

2.10.3 - Ipod Volume Settings

Table 5 shows recommended listening times for different volume levels.

Ipod Volume level	Recommended listening time
10% - 50 %	No hearing loss
60%	18 hours a day
70%	4.6 Hours a day
80%	60 - 90 minutes
95%	5 minutes

Table 5 - Recommended Ipod listening times[30]

With the current issue regarding hearing loss and MP3 players; manufacturers have taken this into account and now Apple amongst others have provided a downloadable piece of software that can be installed onto the Ipod allowing a maximum volume limit to be set.

2.10.4 - Masking

When two or more tones are present the effect known as 'masking' can occur. This particular effect occurs when the individual tones present become difficult or impossible to perceive by the listener. Tones can either be partially or fully masked.

Masking is a problem largely related to headphone use and hearing damage. As mentioned earlier; many MP3 users tend to increase the volume when background noise is interfering with audio from their MP3 players; this is a form of masking and in some cases can cause hearing difficulties during later life.

2.10.5 - Hearing Safety Procedures

Hearing loss is preventable; although it may not be immediate it should be considered for the future. Hearing loss is a natural outcome as we become older, but can be made worse when exposed to unnecessary excessive noise. Various measures can be adopted in order to minimise the effects in our later lives.

Hearing damage can be caused by various causes; these include:

- Noise
- Drugs
- Disease
- Injury

Noise

It is a common belief that only loud noise can damage the ear; this is in fact not true. The inner ear can be damaged by noise even when it doesn't send you a pain signal. Many specialists have stated that if you need to shout to be heard over the noise, then it's potentially damaging. Methods in which to minimise excessive noise levels can include[31]:

- Avoid exposure when possible.
- Consult with occupational health and safety procedures at work if you are concerned about noise levels within the workplace. Current standards state two action levels, 80 dB(A) and 85 dB(A) being the upper level.
- Wear hearing protection when possible and where provided. When levels are above 85 dB(A) legislation state that the employer must provide hearing protection.
- It is important to remember that everyday equipment may be loud enough to cause hearing damage; such as lawn mowers, stereos and power tools.

Drugs

Certain drugs can cause hearing loss as a side effect if taken for more then seven days[31]. Risks are increased and could lead to temporary hearing loss or permanent hearing loss.

Disease

Viral disease such as mumps, rubella, measles and pertussis can cause hearing loss. These symptoms are more likely during childhood, although adults who have not been immunised can run the risk of catching them in their later life. Bacterial diseases such as meningitis can also affect hearing[31]. A tumour which grows on the auditory nerve called 'acoustic neuroma' can cause hearing loss and tinnitus.

Injury

Head injury can cause damage to hearing on a permanent basis; such an injury can cause damage to hair cells which can cause immediate effect or a problem that may occur over a period of time[31].

2.11 - The Control of Noise at Work Regulations 2005

The Control of Noise at Work Regulations 2005 came into force for all industry sectors in Great Britain on 6 April 2006[19] (except for the music and entertainment sectors where they come into force on 6 April 2008).

The aim of the Noise Regulations is to ensure that workers' hearing is protected from excessive noise at their place of work, which could cause them to lose their hearing and/or to suffer from tinnitus (permanent ringing in the ears).

The Control of Noise at Work Regulations 2005 replaces the Noise at Work Regulations 1989 (except for the music and entertainment sectors where the 1989 Regulations will continue to apply until 6 April 2008).

- Lower exposure action values
  - 80 dB(A) $L_{EP,d}$ or $L_{EP,w}$ - i.e. a daily or weekly personal noise exposure of 80 dB(A)
  - 135 dB(C) L_{Cpeak} - i.e. a peak sound pressure level of 135 dB(C)
- Upper exposure action values
  - 85 dB(A) $L_{EP,d}$ or $L_{EP,w}$ - i.e. a daily or weekly personal noise exposure of 85 dB(A)
  - 137 dB(C) L_{Cpeak} - i.e. a peak sound pressure of 137 dB(C)
- Exposure limit values (values include the effect of hearing protection)

- 87 dB(A) $L_{EP,d}$ or $L_{EP,w}$ - i.e. a daily or weekly personal noise exposure of 87dB(A)
- 140 dB(C) L_{Cpeak} - i.e. a peak sound pressure of 140 dB(C)

The daily personal noise exposure levels for each subject have been calculated using the equation 1. The outcome can be seen in the results section.

$$L_{EP,d} = L_{Aeq,Te} + 10\log_{10}\left(\frac{T_e}{T_0}\right)$$

Equation 1 - Daily personal exposure levels[19]

Where:

T_e = duration of the persons working day (seconds)

T_0 = 28,000 seconds (8 hours)

3.0 - Experimental Procedure

The idea of this particular experiment is to initially test at least twenty subjects in relation to MP3 player volume levels with and without the presence of background noise, which in this case is carriage noise from the London Underground.

3.1.1 – Apparatus

Table 6 shows the equipment used throughout the duration of the investigation. All the necessary equipment was calibrated in accordance to the appropriate legislation.

Equipment	Description	Model/Serial N°
Norsonic 121	Octave band sound analyser	????
CEL 282	Sound calibrator	????
B&K speaker	Loud speaker	4224

B&K dummy head	Binaural head and torso with a microphone in each ear	4100 No 2118265
Anechoic chamber	Chamber where all testing was carried out.	-
Apple Ipod	MP3 player with three test tracks	Nano 4GB
Headphones	Bose quiet comfort 1 acoustic noise cancelling headphones	-
Laptop	Sony Vaio installed with Adobe Audition 3	-

Table 6 - Equipment used throughout the investigation

Figure 20 shows the Bose noise cancelling headphones along with the Ipod and the remote control to switch between 'low' and 'high' settings.

Figure 20 – Bose headphones and Ipod

Figure 21 – Nor 121 and Laptop setup

Figure 21 shows the set up of the Norsonic 121 analyser along with the laptop. Figure 22 shows the headphones fitted over the binaural head in order for the 121 analser to read the noise levels. Figure 23 is a general overview of the equipment setup as a whole, the laptop being connected to the B&K loudspeaker via the headphone port on the laptop.

Figure 22 – Binaural head with Bose headphones in place

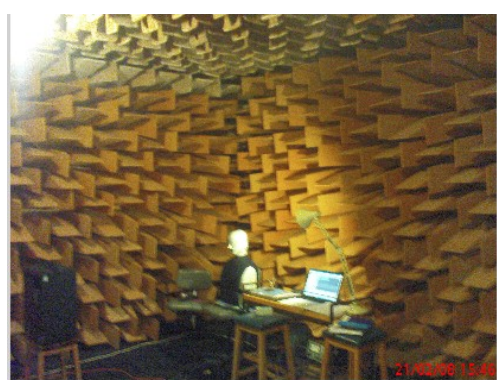

Figure 23 – Equipment set-up

3.1.2 - Equipment Setup

Figure 24 shows the setup of the equipment used throughout the duration of the experiment.

Ideally the experiment should have been carried our using a 'headphone splitter'; this allows you to connect two pairs of headphones to one device, in this case the Ipod. As the Bose headphones are not in production any more it caused a minor setback with testing; this meant testing would take slightly longer than anticipated.

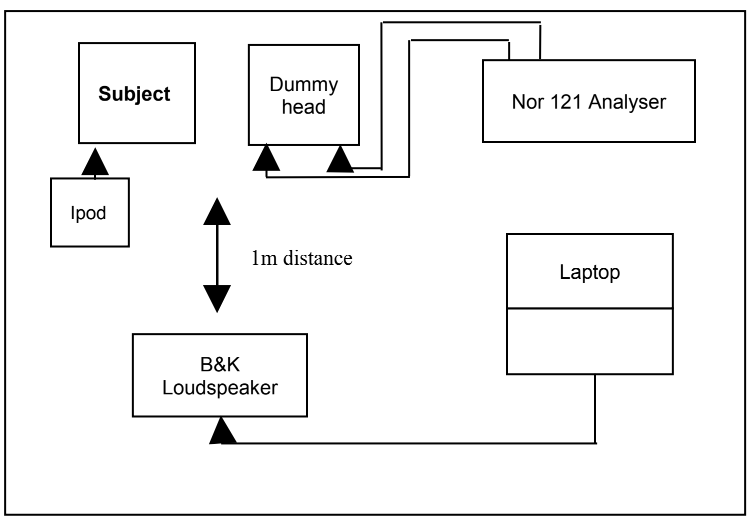

Figure 24 - Block diagram showing the equipment setup

3.1.3 - Questionnaire

Each participant will also complete a questionnaire regarding their individual hearing, use of MP3 players, if any, medical issues and information regarding they're noise exposure both in the past and currently.

The questionnaire has been designed to give information regarding the subject's current state of hearing; this will allow comparisons to be made with the answers given and their actual recorded volume levels.

A copy of the questionnaire along with all the answers can be seen in Appendix 1

3.1.4 - Bruel & Kjaer Binaural Head & Torso Simulator

The head and torso simulator is a mannequin that has a built in ear simulator which produces realistic reproduction of acoustic properties of an average adult. The ear, which can be calibrated, contains a ½" microphone which is connected to a microphone preamplifier with an adaptor.

The binaural head is an important piece of apparatus for the experimental procedure. It will be connected to the analyser to provide data regarding the volume levels emitted via the Bose noise cancellation headphones.

When this particular dummy head was designed the ear canals were not accounted for. Although the ear canal do have an effect when sound enters the ear it was deemed that results will only be affected to a small degree. A later model does account for ear canals which would have been the preferred choice when testing.

3.1.5 - Bakerloo Train Noise

There are various types of noise that could be used as background noise for the experiment that was carried out; it was important to use a 'typical' noise source that would be representative as a whole.

It was decided that as thousands of commuters use the London Underground on a daily basis it would be suitable to use train noise as the background source noise.

The train noise was recorded for use in a very similar project, various findings from the journey have been stated and these include the following:

- The noise levels varied significantly during the journey in relation to the speed of the train[32]; i.e. the faster the train travelled the louder the background noise became.
- During a typical journey, the train would travel at its maxima permissible speed as often as possible; typically for around 2 minutes between each stop[32].

- The worst case scenario was used to reflect the most common noise levels, in this case when the train was travelling at maximum speed. Typical noise levels were measured at 84 $dBL_{Aeq,2min}$, with the highest single event measured at 96 dBL_{AFmax}[32].

3.1.6 - Music and Speech Tracks

As part of the investigation each subject will listen to three different tracks, as outlined below. The tracks chosen are due to their varying spectral content. Figure 25 shows the octave band frequency content of each of the tracks over a period of one minute; with the overall output being is 85 dB(A).

The tracks used throughout the procedure are as follows.

- Madonna – Get into the grove (Pop)
- Skidrow – You've gone wild (Rock)
- BBC News podcast (Speech)

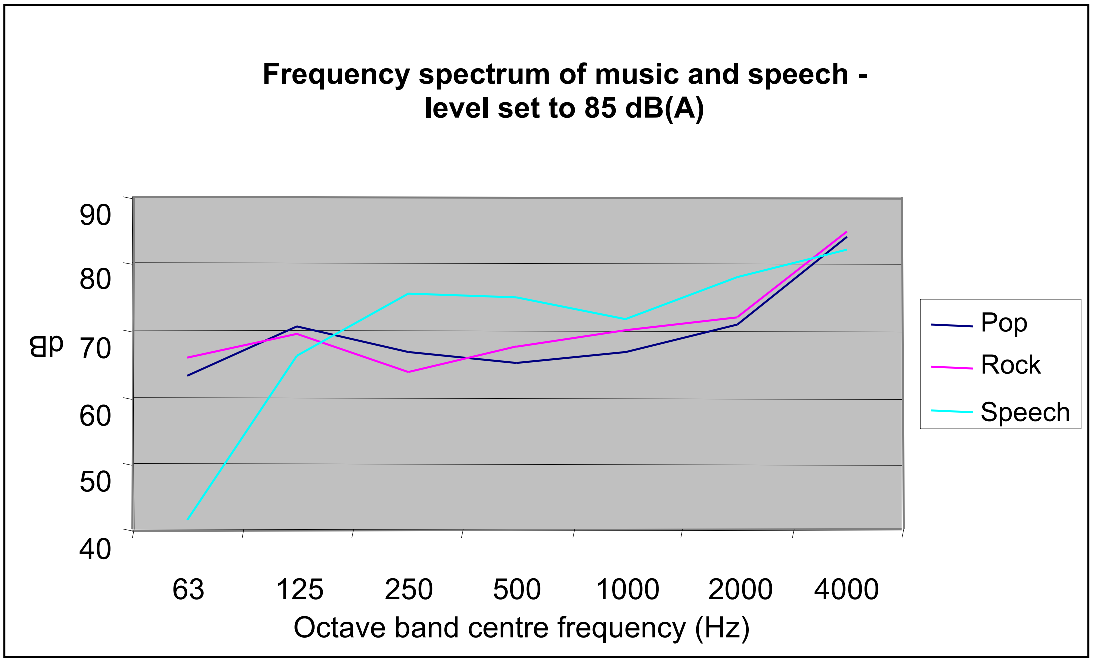

Figure 25 – Frequency spectrum of the tracks used throughout the experiment[32]

As it can be seen from figure 25 all the tracks are dominant in the high frequency range. The frequency content of the speech track is due to the fact that the content is spoken by a female and it is known that the female voice generally contains higher frequency content when compared to the frequency content of a male's voice.

The frequency content of the pop and rock tracks are fairly similar across the frequency range. The slight differences occur between 125 Hz and 250 Hz for the pop track; which shows the frequency content between these two bands to be slightly higher of those on the rock track. In regards to the rock track; there is an increase between 500 Hz and 1000 Hz, after this period both the pop and rock track have very similar frequency content towards the high end of the spectrum.

3.2 - Methodology

Before testing commenced the binaural dummy head and torso needed to be calibrated. The calibration procedure was conducted using a CEL 282 calibrator. Calibration was set at 114 dB; this was also carried out at the end of the testing procedure to ensure that there was no significant drift throughout the experiment.

The experiment was conducted in two stages. Firstly, the subject will listen to three different tracks on the Ipod using the Bose Noise Cancellation headphones. The tracks range in terms of their genre; they include pop and rock music and a podcast speech track. The procedure will be carried out within the anechoic chamber; in order to eliminate any background noise from around the vicinity. Any additional background noise would jeopardise the test resulting in inaccurate results.

The subject will initially listen to each track individually using the headphones. They will adjust the volume on the Ipod accordingly to their individual taste. Once the level has been set, the level will be recorded by placing the headphones on the binaural head, which will be connected to the Nor 121 analyser.

The second stage of the procedure is extremely similar to the first stage, the addition of a loudspeaker emitting previously recorded London Underground train noise will be emitted at a level of around 82 dB(A). The amp will be placed at 1 meter away from the subject. Once the train noise is emitted the subject will listen to the same tracks as before and again they will adjust the volume on the Ipod accordingly. From initial thought, it is expected that the volume levels will increase when the train noise is present; further analysis of this will be analysed when the testing is complete.

The train noise used for this experiment was recorded on the Bakerloo line on the London Underground.

Figure 26 shows a screen shot of the Adobe Audition 3. This was the software that was used to play the background noise with was fed into the loudspeaker via the headphone socket located on the laptop. Figure 26 shows the looped train noise track for both the left and right outlets.

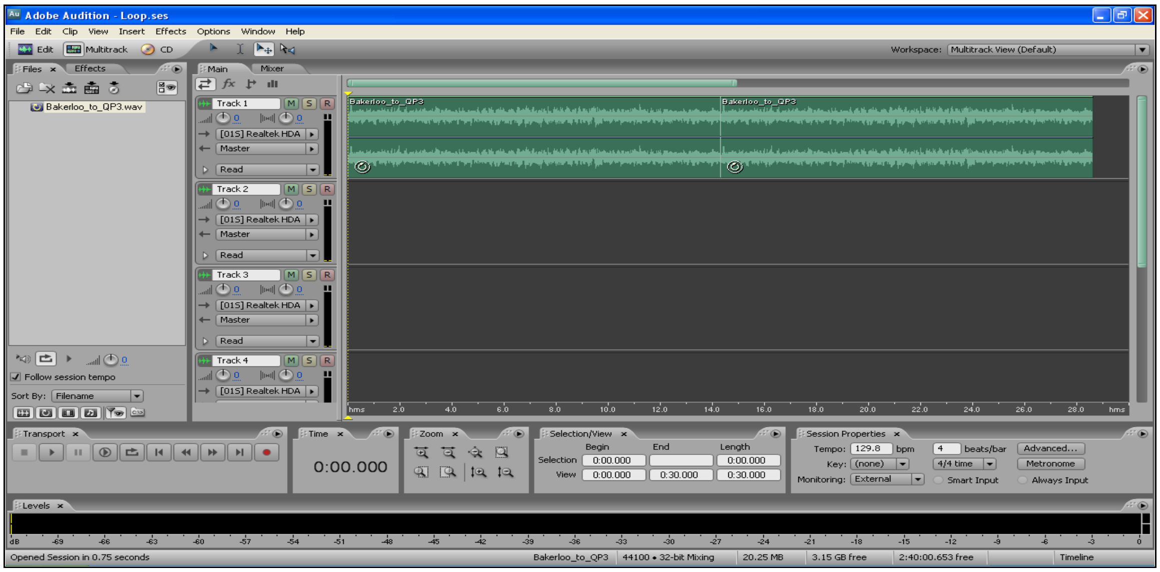

Figure 26 – Screenshot of the train noise tracks loaded into Adobe Audition 3

4.0 - Results

4.1 - Questionnaire Results

With this information at hand, it can provide an insight into why each individual may listen to MP3 players at the volumes they chose. The following brief gives information regarding the findings from the results that have main relevance to the investigation. A full summary of the results can be seen in Appendix 1.

4.1.1 - Age and Sex

After analysing the results it was found that the most common age group tested was 21-30 year olds. This was an expected result as testing took place during term time; although there were subjects from the older age groups which was encouraging. The 21-30 years old age group accounted for 55% of the subjects. The only female accounted for was within this particular age group.

Following this, the next common age groups that accounted for 15% of the subjects was the 31-40 and 51-60 age groups. The next age group was the 41-50 year old age group, this accounted for 10% of subjects. The final age group was the 61+ year old group, this only accounted for 5% of results. Although there are a small number of MP3 player users in the higher age category, it does not represent the typical users of MP3 players.

4.1.2 - Hearing

In regards to the subject's state of hearing it was found that 70% of subjects regarded their current state of hearing as 'good'; with the remaining 30% stating they have 'little trouble'.

65% of the subjects have had their hearing tested. Of the subjects tested 38% had their hearing tested within the last year. Another 38% had theirs tested in the last 1-4 years and the remaining percentage had their hearing tested more than fours years ago. It was also found that none of the tested had had to wear a hearing aid.

4.1.3 - Medical History

The results show that none of the subjects suffered from earache; although 10% of subjects stated that they suffer from 'ringing' in the ears and 5% suffered 'buzzing'. One of the subjects that stated that they suffer from 'ringing' also stated that it occurs 'always'. This particular subject has 'little trouble' with hearing and has also worked in construction, has played the piano for 40 years, commutes to work on a motorbike and also listens to an MP3 player once a week. Bearing all this information given it does give indication that this particular subject is a type of subject that could be experiencing troubled hearing. None of the subjects have had a consultation with a GP regarding problems regarding the ear.

4.1.4 - Noise Exposure

As stated earlier the majority of participants were students, accounting for 45%. Lab technicians and lecturers accounted for 25% while the remaining subjects were working as engineers within various engineering disciplines. When asked about noise exposure within the last month 20% were exposed to loud noise on the day they took part in the experiment. While 27% were exposed to loud noise the previous day. Any subjects exposed to loud noise on the day of testing or the previous day is likely to be suffering from temporary threshold shift. 33% of participants were exposed to loud noise the previous week and the final 20% stated they were exposed within the last month.

Another important question raised was weather the subjects played any musical instruments. Only 20% stated they did play; of which 13% stated they have been playing their respective instruments for forty years and the remaining participants playing for 15 years. The instruments stated by participants who have been playing for forty years are the guitar, banjo and piano respectively. The remaining subject stated to playing drums, electric guitar and oboe. Playing instruments for a number of years poses the risk of hearing loss and this being taken into account can provide details that these particular subjects may listen to MP3 players at louder volumes to compensate for hearing loss that may have occurred from playing instruments for a number of years.

4.1.5 - Use of MP3 players

This particular section was considered to be an important section as it related to the principle behind this particular dissertation.

20% of participants stated that they don’t use MP3 players, whilst results show the usage for the remaining subjects range from everyday to once a month.

- **Age 21-30**

This was the most common age group that used MP3 players. The following show the usage of their MP3 players.

- 36% of subjects stated using on a daily basis
- 9% admitted to using it four to five times a week
- 27% said they use it between two or three times a week.
- 9% stated to using it once a week
- 18% using on a monthly basis

- **Age 31-40**

15% of subjects tested were within this age bracket. The following points show the usage of MP3 players for this particular age bracket.

- 33% use their MP3 player two or three times a week
- 33% use their MP3 player once a month

- **Age 41-50**

This was the second most popular age group. The subjects who use MP3 players all listened to it for between fifteen and thirty minutes. The following points detail their personal usage.

- 50% of subjects use their MP3 players once a week
- 25% claimed to use it two or three times a week

- **Age 60+**

The subjects within this age bracket stated that they did not use MP3 players.

4.2 - Noise Cancellation and Ipod Settings

The headphones have two settings, 'low' and high'. The subjects set volume levels accordingly using both the settings. It was found that when using the 'high' setting the noise was being amplified, where as on the 'low' setting the noise cancellation would become active.

It was initially found that the Ipod had been fitted with a volume limiter which was affecting the results and was also found to be unsuitable when listening to the tracks whilst the train noise was present. This problem was soon rectified by adjusting the settings and removing the limiter for the time being.

4.3 - Measured Levels

4.3.1 - Speech – No Background Noise

Figure 27 shows the overall measured noise levels when the subjects were listening to speech without the presence of simulated background noise. The levels shown are from the first fifteen seconds of the track.

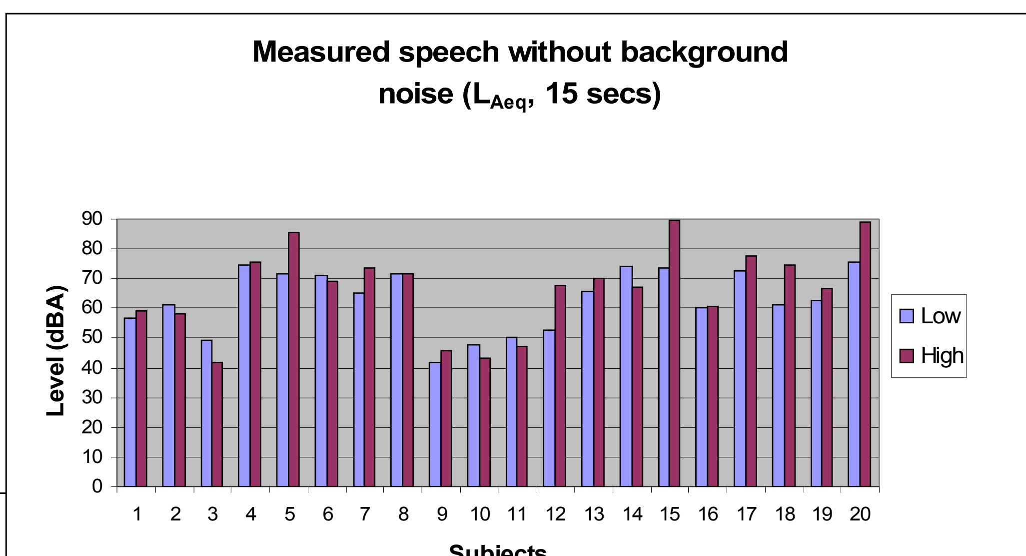

Figure 27 – Speech results without background noise

The graph shows results for the standard settings on the headphones. On the 'low' setting the highest level recorded was 75.4 dB(A) and on the 'high' setting the highest recorded was 89.3 dB(A).

4.3.2 - Pop – No Background Noise

Figure 28 shows the overall measured noise levels when the subjects were listening to pop music without the presence of simulated background noise. The levels shown are from the first fifteen seconds of the track.

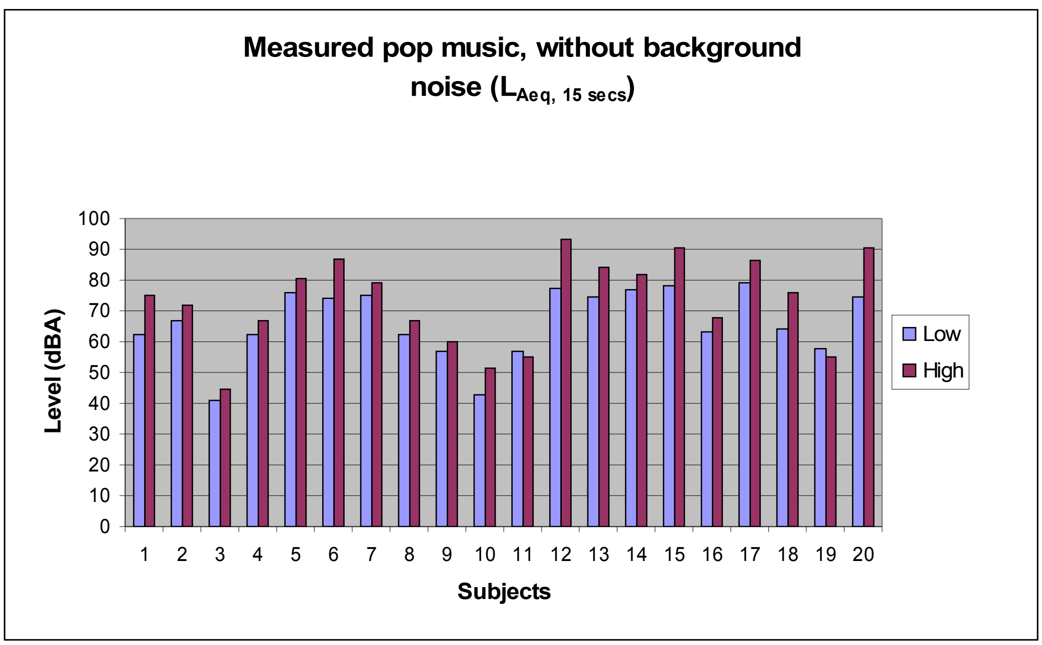

Figure 28 – Pop music results without background noise

The graph shows results for the standard settings on the headphones. On the 'low' setting the highest level recorded was 79.1 dB(A) and on the 'high' setting the highest recorded was 93.2 dB(A).

4.3.3 - Rock – No Background Noise

Figure 29 shows the overall measured noise levels when the subjects were listening to rock music without the presence of simulated background noise. The levels shown are from the first fifteen seconds of the track.

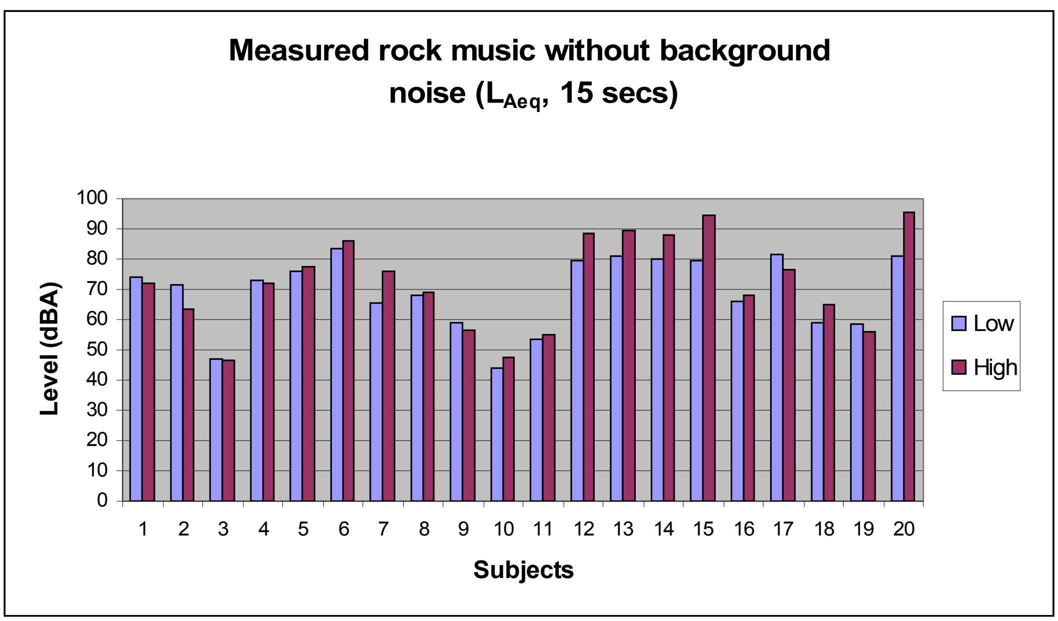

Figure 29 – Rock music results without background noise

The graph shows results for the standard settings on the headphones. On the 'low' setting the highest level recorded was 83.6 dB(A) and on the 'high' setting the highest recorded was 95.4 dB(A).

4.3.4 - Speech – In the Presence of Train Noise

Figure 30 shows the overall measured noise levels when the subjects were listening to rock music in the presence of simulated background noise. The levels shown are from the first fifteen seconds of the track.

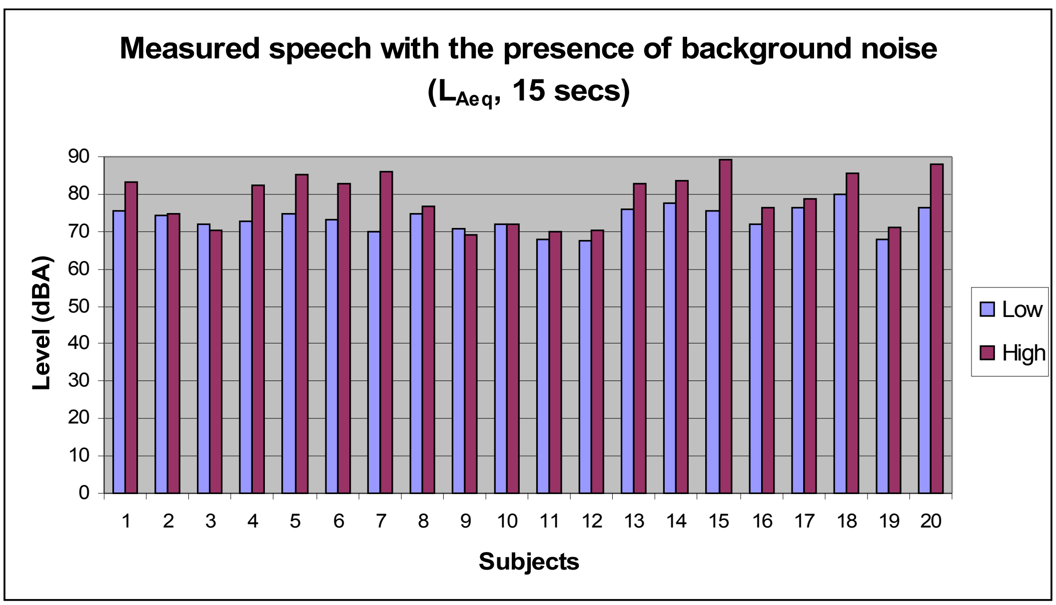

Figure 30 - Speech results in the presence of background noise

The graph shows results for the standard settings on the headphones. On the 'low' setting the highest level recorded was 80.0 dB(A) and on the 'high' setting the highest recorded was 89.0 dB(A).

4.3.5 - Pop music – In the Presence of Background Noise

Figure 31 shows the overall measured noise levels when the subjects were listening to rock music in the presence of simulated background noise. The levels shown are from the first fifteen seconds of the track.

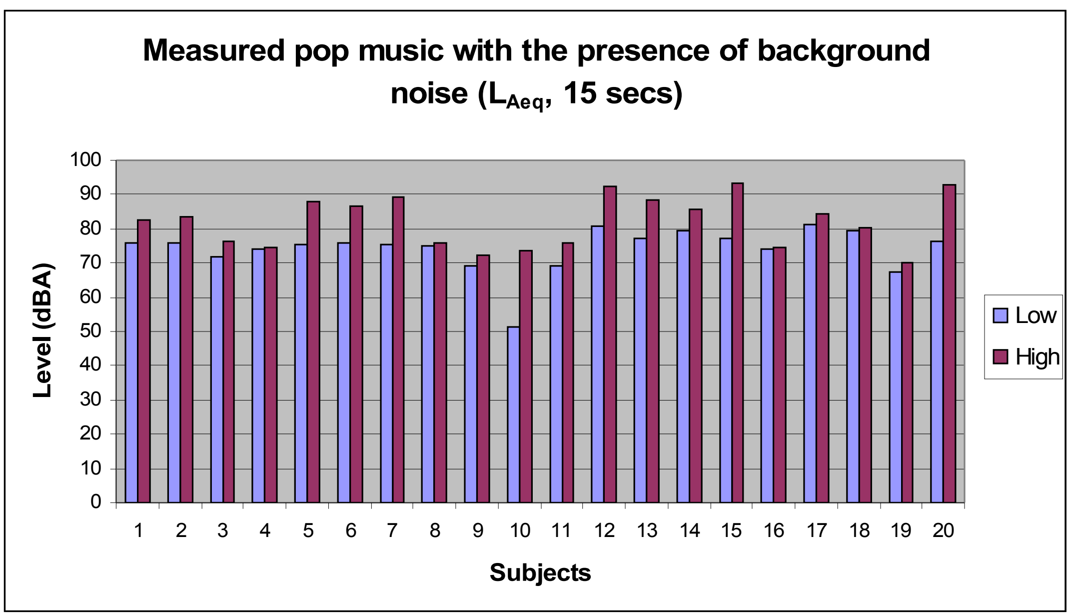

Figure 31 – Pop music results in the presence of background noise

The graph shows results for the standard settings on the headphones. On the 'low' setting the highest level recorded was 81.4 dB(A) and on the 'high' setting the highest recorded was 93.5 dB(A).

4.3.6 - Rock music – In the Presence of Background Noise

Figure 32 shows the overall measured noise levels when the subjects were listening to rock music in the presence of simulated background noise. The levels shown are from the first fifteen seconds of the track.

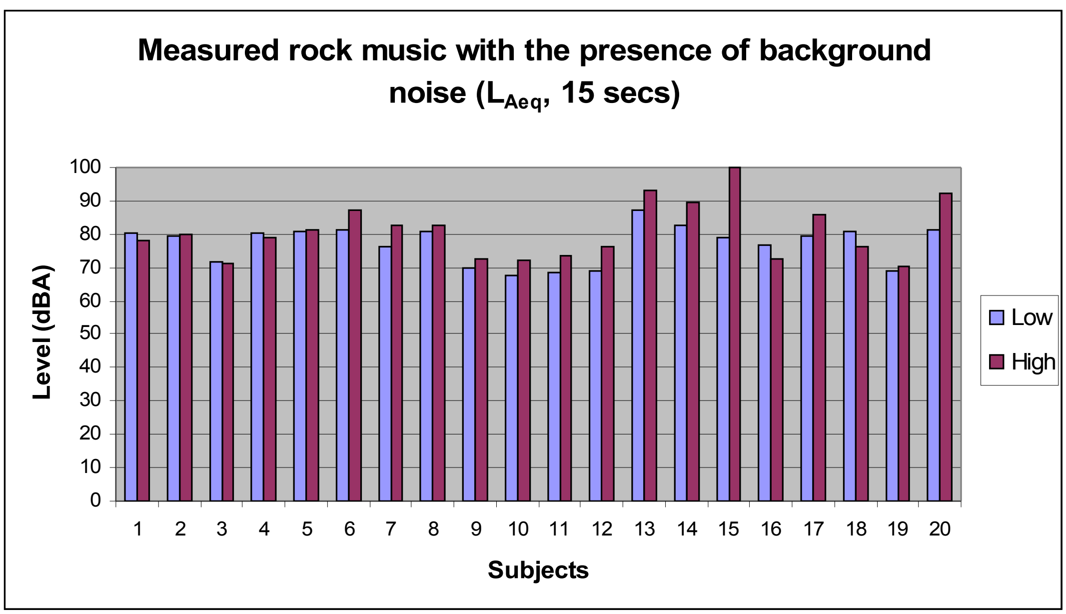

Figure 32 - Rock music results in the presence of background noise

The graph shows results for the standard settings on the headphones. On the 'low' setting the highest level recorded was 87.3 dB(A) and on the 'high' setting the highest recorded was 99.9 dB(A).

The results show that the majority are under 80 dB(A), as with experiments, they're will always be a few extreme results and this experiment is no different. The extreme results are likely to occur in each track they listened to

4.4 - Summary of Results

4.4.1 - Lowest and Highest Volume Levels

Table 7 show the lowest and highest volume levels from the investigation. The results show the levels from both the 'low' and 'high' headphone settings for each type of track.

		Track	Speech		Pop		Rock	
		Level (dB(A))	Lowest level	Highest level	Lowest level	Highest level	Lowest level	Highest level
No Noise	Headphone setting	Low	41.9	75.4	41.0	79.1	43.9	83.6
		High	42.0	89.3	44.5	93.2	46.7	95.4
Train Noise	Headphone setting	Low	67.6	69.1	51.3	69.9	67.8	87.3
		High	80.0	89.0	81.4	93.5	70.5	99.9

Table 7 - The lowest and highest volume levels measured

Looking at the 'low' setting it shows that only two of the results have exceeded the action levels stated in the 'Noise at Work Regulations 2005'. One of these results has exceeded the upper action level, in this case 87.3 dB(A).

When the subjects were using the 'high' setting on the headphones, results changed dramatically in some cases. Looking at table 7 it shows that all the highest levels are well above the lower and upper noise regulation limits; one subject reaching a level of 99.9 dB(A). All the results shown above have succeeded the upper threshold value of 85 dB(A) apart from one result, which was measured at 83.6; although this has exceeded the lower threshold value. Some of these levels are a cause for concern, especially the levels that have exceeded the upper threshold. It should be noted that there will always be a small percentage of users that enjoy listening to music at high volumes, and regardless of the headphones some subjects will have a habit of listening to music on such levels giving little consideration to the affect on their hearing.

4.5 - Measured Difference

4.5.1 - Speech

Figure 33 shows the level difference for each subject when listening to the speech track in the presence of train noise.

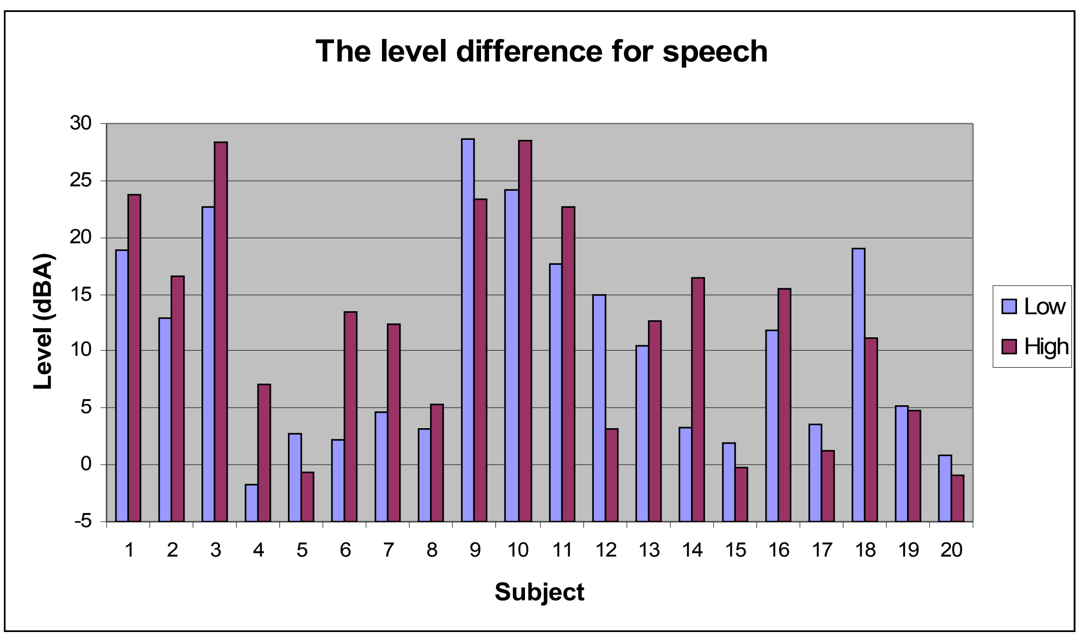

Figure 33 - Level difference for speech track

The lowest difference measured for the low settings was recorded at -1.7 dB(A), where as the largest difference on the low setting was 28.7 dB(A). The lowest measured results when the headphone settings were set to high was -0.9 dB(A), while the largest measured difference was 28.5 dB(A).

4.5.2 - Pop

Figure 34 shows the level difference for each subject when listening to pop music in the presence of background noise.

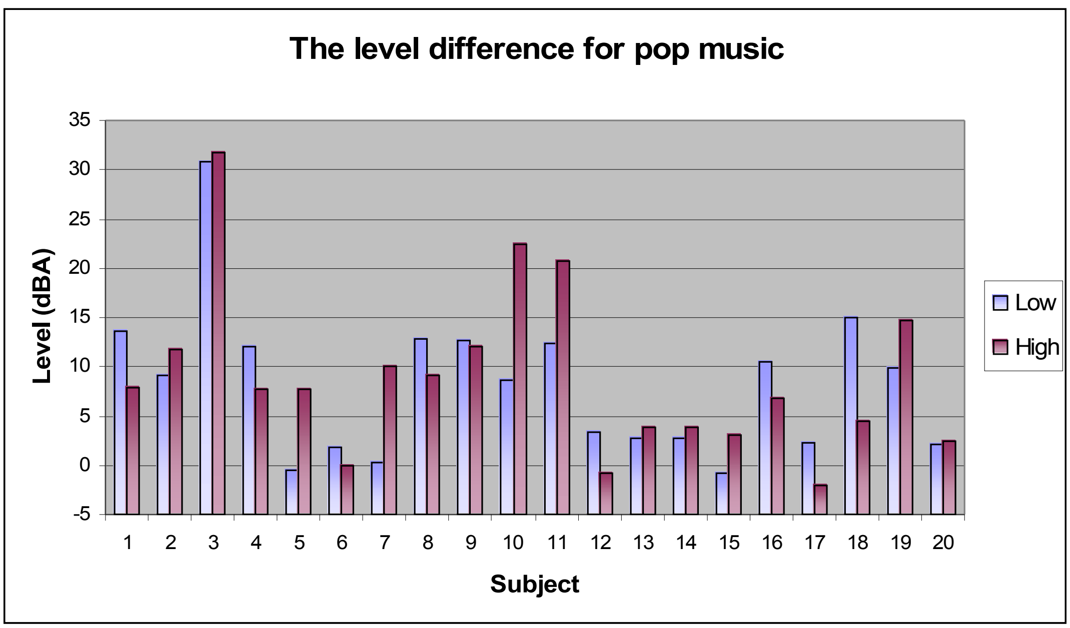

Figure 34 – Level difference for pop music

The lowest difference measured for the low settings was calculated at -0.8 dB(A), where as the largest difference on the low setting was 30.8 dB(A). The lowest measured results when the headphone settings were set to high was -2.1 dB(A), while the largest measured difference was 31.8 dB(A).

4.5.3 - Rock

Figure 35 shows the level difference for each subject when listening to rock music in the presence of background noise.

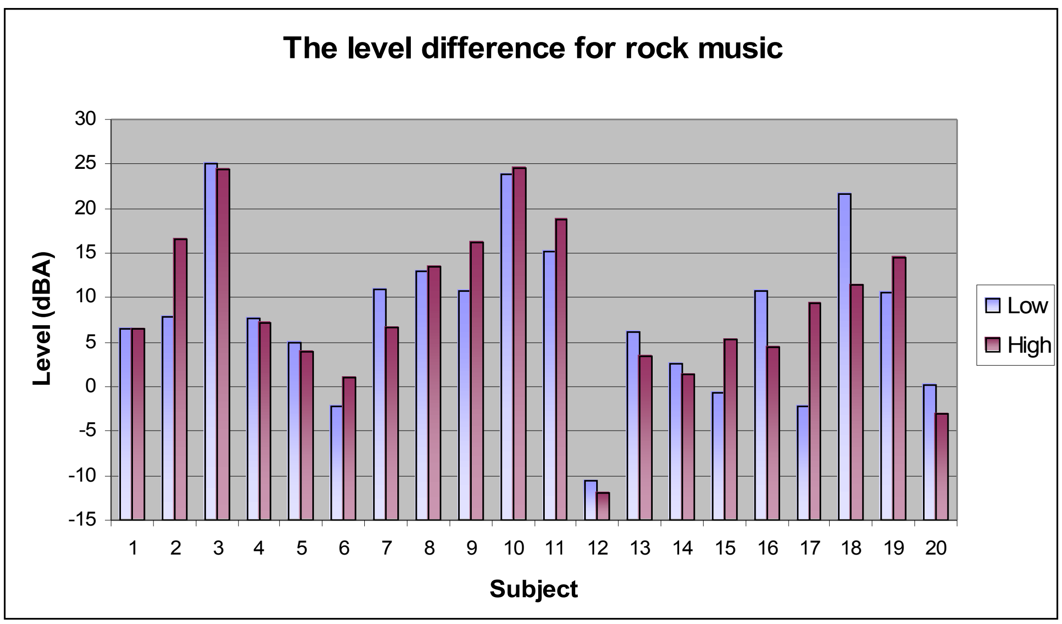

Figure 35 – Level difference for rock music

The lowest difference measured for the low settings was calculated at -10.5 dB(A), where as the largest difference on the low setting was25 dB(A). The lowest measured results when the headphone settings were set to high were -11.9 dB(A), while the largest measured difference was 24.6 dB(A).

4.6 - Averages

4.6.1 - Mean

The mean value is a fairly common statistic and is computed by adding all the values up in question and then dividing the answer by the total number of values; in this case twenty as twenty subjects have been tested. The disadvantage with using the mean value is that the final result can be misleading as extremely high values or low values can change the result significantly[33]. Therefore it has been stated that the mode or median averages are more effective and realistic methods that should be employed.

4.6.2 - Mode

This is the value that has occurred the most times from the data that is currently being analysed.

4.6.3 - Median

This value is calculated by putting all the data in numerical order, smallest to largest and then locating the middle number from that list gives the median value.

4.6.4 - No Noise

Table 8 shows the mean, mode and median averages from the results when background noise wasn't present.

	Speech		Pop		Rock	
	Headphone setting					
	Low	High	Low	High	Low	High
Mean	63.0	66.7	66.1	73.1	69.0	72.2
Mode	64.1	68.4	65.6	75.5	72.1	72.0
Median	#N/A	#N/A	62.2	#N/A	81.2	#N/A

Table 8 – Average results without the background noise

Looking at these averages it shows that the majority of the results have not exceeded the limits as stated in the noise at work regulations 2005. All the results are comfortably below the stated thresholds. The median result for the rock track has exceeded the lower action level by just over 1 dB.

4.6.5 - Simulated Background Noise

Table 9 shows the averages of the results whilst the background noise was present.

	Speech		Pop		Rock	
	Headphone setting					
	Low	High	Low	High	Low	High
Mean	73.4	78.9	74.2	82.0	77.1	80.9
Mode	73.8	80.6	75.7	83.2	79.3	79.5
Median	71.9	#N/A	77.2	74.5	80.8	76.4

Table 9 – Average results in the presence of background noise

When comparing this set of averages with the averages when background noise was not present it can be seen that there is a large difference in the results. The averages have increased, with all results in the 70's and 80's region. There are five cases where levels have exceeded 80 dB(A), but these results have not significantly topped the level.

4.7 - Daily Noise Exposure $L_{EP,d}$ – No Noise

The daily personal exposure level has been calculated for each subject. The levels were calculated by using the equation shown in the noise at work regulations 2005. Table 10 show the results from carrying out the calculations, the levels that are border line of the lower action level or have exceeded the lower and upper levels have been highlighted.

Subject	Speech		Pop		Rock	
	Low $L_{EP,d}$	High $L_{EP,d}$	Low $L_{EP,d}$	High $L_{EP,d}$	Low $L_{EP,d}$	High $L_{EP,d}$
1	48	50	54	66	65	63
2	52	49	58	63	62	54
3	40	33	32	36	38	38
4	66	66	53	58	64	63
5	63	77	67	71	67	68
6	62	60	65	78	75	77
7	56	65	66	70	56	67
8	63	62	53	58	59	60
9	33	37	48	51	50	47
10	39	35	34	42	35	38
11	41	38	48	46	44	46
12	44	58	68	84	70	79
13	57	61	66	75	72	81
14	65	58	68	73	71	79
15	65	80	69	81	71	86

16	51	52	54	59	57	59
17	64	69	70	77	73	68
18	52	65	55	67	50	56
19	54	58	49	46	49	47
20	66	80	65	82	72	86

Table 10 – Calculated $L_{EP,d}$ without background noise

Borderline – 79 dB	First action level 80-84 dB	Higher action level, at least 85 dB

It was found after some research that the average time for commuters in London takes around 60 minutes; therefore 3600 seconds is the figure that has been used in the equation to work out the daily exposure levels. It has been assumed the remainder of the day the subject has been working or studying in quiet conditions.

The results in table 10 show that the majority of users don't exceed the threshold levels, although a number of subjects are either borderline with the lowest threshold limit or within the lower limit or in a few cases above the higher limit.

Subject 12 recorded the highest level at 84 dB(A) whilst listening to the pop track while the headphone settings were on 'high'. Whilst checking the subjects questionnaire results it showed that the subject has stated that their hearing 'good' and doesn't suffer from ringing or buzzing. When asked about the volume level when listening to the Ipod the subject has indicated this by saying 'high', from this it's being assumed that the user listens to their Ipod on maximum or near to maximum on a daily basis for around 30 minutes.

Subject 13 was aged between 51-60 therefore presbycusis has been taken into account. The subject stated they had 'little trouble' with their hearing but didn't suffer from ringing or buzzing. The subjects level reached 81 dB(A) while listening to the rock track on the high setting. It should also be noted that the subject was a keen musician, stating that have played the guitar for 40 years and the banjo for 10 years; it was not mentioned weather the guitar was electric. It is common and has been mentioned within this report that musicians are at high risk of causing hearing damage over the years of playing. With these considerations taken into account as well as the age, it provides a good basis as to why levels across the board were of a high nature; although levels didn't generally exceed threshold limits.

Subject 15, aged between 21-30 had no previous hearing conditions and didn't suffer from ringing or buzzing. This particular subject had levels of 80 dB(A) on the speech track, 81 dB(A) on the pop track and 86 dB(A) on the rock track, the setting for all these results were set to high. The subject admitted to going to a nightclub the previous night, this meaning that they were suffering from temporary threshold shift. Other information showed that the subject listens to their Ipod for over 90 minutes daily with the volume set to high.

The levels that were borderline or exceeded the threshold limits of subject 20 were identical of those of subject 15. The subject has no previous history of hearing problems. Although the subject had stated working within the manufacturing and construction industry; this possibly causing some form of hearing damage.

4.8 - Daily Noise Exposure $L_{EP,d}$ – Simulated Background Noise

Table 11 shows the daily noise exposure for each subject in the presence of background noise.

Subject	Speech		Pop		Rock	
	(Low) $L_{EP,d}$	(High) $L_{EP,d}$	(Low) $L_{EP,d}$	(High) $L_{EP,d}$	(Low) $L_{EP,d}$	(High) $L_{EP,d}$
1	67	74	67	74	71	69
2	65	66	67	75	70	71
3	63	61	63	67	63	62
4	64	74	65	66	71	70
5	66	76	67	79	72	72
6	64	74	67	78	72	78
7	61	77	67	80	67	74
8	66	68	66	67	72	74
9	62	60	60	63	61	64

10	63	63	42	65	59	63
11	59	61	60	67	60	65
12	59	62	72	83	60	67
13	67	74	68	79	78	84
14	69	75	71	77	74	81
15	67	80	68	85	70	91
16	63	67	65	66	68	63
17	67	70	72	75	70	77
18	71	77	70	72	72	67
19	59	62	59	61	60	62
20	67	79	68	84	72	83

Table 11 - Calculated $L_{EP,d}$ In the presence of background noise

Borderline – 79 dB	First action level 80-84 dB	Higher action level, at least 85 dB

These results show that there are a small number of subjects that are borderline of the threshold limits or have exceeded either the lower or higher limits.

Subjects 12, 13 and 15 are either borderline, exceeded the levels or a combination of the two. These subjects had levels which were relatively high when the headphone settings were set to 'low'. There questionnaire results were discussed earlier and there are clear signs that these particular subjects are suffering from some degree of hearing loss.

Looking at the table as a whole, it shows that a high percentage of the subjects are unlikely to suffer from long term hearing damage as levels are acceptable.

4.9 - Summary of Results

The predictions made prior to starting the investigation have been proved for the majority of subjects. It was predicted that introducing the background noise would increase the volume levels for each of three tracks. It was predicted that the biggest increase in volume would be on the speech track; this is because in order to understand speech properly the subject needs to be able to hear it clearly and with the introduction of background noise many of the subjects are instinctively going to increase the volume in order to understand what is being said.

It must be noted that because the tracks chosen were not subject dependant some of the results may not be a true indication of results. It may be the case that some subjects set the volume low because the chosen tracks were not the typical genre of music they were used to. With this said, the procedure was thoroughly described to each subject and was mentioned not to let the genre of music used to alter the volume.

5.0 - Comparisons between Bose Noise Cancelling headphones Ipod Headphones

A similar project using different headphones was carried out under the same conditions, although it was done on a slightly larger scale with thirty three subjects being tested. It was suggested throughout the experimental stage that the results gained from these tests may be compared with results from a previous project. It was this reason why the same tracks were used on both projects in order to keep similarities between the projects.

The idea was to see the level difference if any between the results gained from the project using standard Ipod headphones with the results gained from using Bose noise cancelling headphones. The main concept of noise cancelling headphones is to allow the user to listen to music at a lower level due to it's ability to reduce background noise. Ideally the results when using the noise cancelling headphones should be lower when compared with the Ipod headphones.

5.2 - Ipod and Bose comparisons

Table 12 shows the comparisons with the Ipod headphones and the Bose headphones with the settings adjusted to 'low'. The results shown in 'black' are those of the Ipod headphones and those shown in 'red' are from the Bose noise cancelling headphones; this corresponds to both tables 12 and 13.

Track	Without background noise, dB(A)		With background noise, dB(A)	
	Lowest	Highest	Lowest	Highest
Speech	46.1 41.9	84.2 75.4	84.6 67.6	98.3 69.1
Pop	60.3 41.0	90.2 79.1	84.3 51.3	104.5 69.9
Rock	61.5 43.9	94.4 83.6	85.9 67.8	106.1 87.3

Table 12 – Ipod and Bose noise cancelling headphone comparisons

When the Bose noise cancelling headphones are set to low it shows that there is a significant difference with the results when compared with the results gained from the standard Ipod headphones. In every case the results from the Bose headphones are lower and in a few cases these is a significant difference.

This potentially shows that there is a difference between in ear headphones and circum-aural headphones. As mentioned earlier, headphones that fit over the ear instantly provide an elimination of ambient noise meaning users can reduce the volume instantly. With the addition of noise cancelling technology the reduction can be made further.

Table 13 shows the comparisons with the Ipod headphones and the Bose headphones with the settings adjusted to 'high'

Track	Without background noise, dB(A)		With background noise, dB(A)	
	Lowest	Highest	Lowest	Highest
Speech	46.1 42.0	84.2 89.3	84.6 80.0	98.3 89.0
Pop	60.3 44.5	90.2 93.2	84.3 81.4	104.5 93.5
Rock	61.5 46.7	94.4 95.4	85.9 70.5	106.1 99.9

Table 13 - Ipod and Bose noise cancelling headphone comparisons

Again, when looking at the results when the setting has been switched to 'high' it shows that the results differ and in some cases significantly between the two types of headphones. Some of the results are significantly higher than the 85 dB(A) limit, but it is a common finding whenever experiments such as this are carried out there will always be a small percentage of results that have an extreme result, which at times doesn't show the true extent of the whole situation.

Looking at the results as a whole, it does show that levels measured are at acceptable levels in which case this is little concern regarding hearing damage.

6.0 - Conclusion

In conclusion it shows that subjects using noise cancelling headphones do generally listen to audio at a lower volume than those who use in ear headphones. This shows that the idea behind the noise cancelling headphones is valid and does have a positive effect on the overall use of headphones.

From research it has been established that more research and the need to stress the importance of the effects of prolonged use of personal stereo's needs to be more widespread, so that the dangers are known worldwide.

Noise levels found from the subjects aren't as such a concern when compared to the results gained from the standard Ipod headphones. Warnings on MP3 packages should be considered, this is an important issue, especially for the younger generation as it is likely that younger subjects are less likely to consider the implications of listening to audio at high volume levels.

As stated in the literature review, some experts have said that it doesn't matter what kind of headphone is used, it is the volume the subject listens to their MP3 player is of major concern. Some of the results gained from this experiment show that although the headphones are designed to reduce ambient noise some subjects still listen to music at high levels.

6.1 - Further work

This particular topic is still of wide interest and from the lack of research at present today it is an area which needs development in order to show what the potential health risks are.

Ideally an experiment similar to this to be carried out with a larger number of subjects would be beneficial. The larger the number of subjects enables more analysis with the results. It may also be an idea to test the subjects using a variety of background noise.

As the number of MP3 users are set to continue in the future, it is of uttermost importance that procedures are carried out in order to find the long term effects. It should also be of importance to the brands selling MP3 players, introducing a limited volume that can't be altered may be the key.

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Appendices

MP3 Player Questionnaire

Personal Details

Surname………………………………. **Initials**…………..…

Sex Male Female

Age <20 21-30 31-40 41-50 51-60 >60

Hearing

Which statement best describes your hearing?

Good Little trouble Lot of trouble Deaf

Have you had your hearing tested?

Yes No

If yes, when was the last time it was tested?

<1 year 1-4 years >4 years

Have you ever worn a hearing aid?

Yes No

Is there any history of hearing loss within your family?

Yes No

If you have chosen 'Yes' please describe the problems.

Medical History

Do you have a history of any of the following?

Earache Yes / No
Ringing Yes / No
Buzzing Yes / No

If 'Yes' how often does it occur?
Always Daily Weekly Monthly

Do you have a history of any of the following?

Head injury, loss of consciousness, head or ear surgery Yes / No
Consultation of GP regarding ear problems Yes / No
Discharge/running from ears Yes / No

Do you take any prescribed medication? Yes / No

If you have chosen 'Yes' please describe.

Noise Exposure – Occupational & Recreational

Present occupation…………………………………………………………………………………...

Do you play any musical instruments?

Yes No

If you have chosen 'Yes' please state the instrument/s and the length you've been playing for.

Have you had any exposure to loud noise? (E.g. Concert/club)

Today Previous day Previous week Previous Month

If within the last 7 days, please describe?

How did you travel here today?

Train Car Tube Bus Walk

Have you ever worked in any of the following sectors?

Armed forces	Yes / No
Manufacturing	Yes / No
Construction	Yes / No
Other (Noisy sectors)	…………………………………………………………….

How would you rate your noise exposure to the following categories?

Home	Quiet	1	2	3	4	5	6	7	8	9	10	Loud
Work	Quiet	1	2	3	4	5	6	7	8	9	10	Loud
Leisure	Quiet	1	2	3	4	5	6	7	8	9	10	Loud

Use of MP3 players

How often to you listen to a personal stereo/MP3 player?

Daily	Once a week	Never
2-3 times a week	Once every 2 weeks	Other…………………….
4-5 times a week	Once a month	

When using a personal stereo, how long do you listen to it?

<15 mins 15-30 mins 30-60 mins Other (Please specify)……………………………..

How would you describe the volume level when you are using your MP3 player?

When in a noisy area do you increase the volume of your MP3 player?

Yes / No

What do you listen to when using your personal stereo?

Rock Pop R ‘n’ B Dance Speech Other…………..

When do you use your personal stereo?

Commuting At work At home

If you have 'Communing' please state method of transport?

If you have chosen 'At work' please choose one of the following.

Office Manufacturing Retail Construction Other…………..

Thank you