# REVIEW OF LITERATURE ON HEARING DAMAGE BY PERSONAL STEREO

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## ABSTRACT

The technological development within personal stereo systems, such as MP3 players, e.g. iPods, has changed music listening habits from home entertainment to everyday and everywhere use. The technology has developed considerably, since the introduction of cassette players and CD walkmans, and high-level low-distortion music is produced by minimal devices. In this paper, the existing literature on effects of personal stereo systems is reviewed, incl. studies of exposure levels, and effects on hearing. Generally, it is found that the levels being used are of concern, which in one study [1] is demonstrated to relate to the specific use in situations with high levels of background noise. Another study [2], demonstrates that the effect of using personal stereo is comparable to that of being exposed to noise in industry. The results are discussed in view of the measurement methods for noise exposure used, and technical issues that may explain the high exposure levels.

## 1. INTRODUCTION

The major part of our knowledge about noise-induced hearing loss relates to industrial noise exposure. This experience is hard-earned. Industrial workers exposed to high sound pressure levels are known to be at risk, and hearing protection devices shall be offered and used, if the level exceeds a certain limit given by national legislation. Also other professions may include the risk of suffering hearing damage. Musicians are exposed to high sound pressure levels, depending on the music and instrument they play, and they will often feel their performance obstructed, if hearing protection is worn.

Less attention has historically been given to exposures from leisure activities, where the individual–usually unknowingly–controls the exposure parameters. There has been little reason to worry about these, and the primary concern has–with good reason–been firearms and shotguns for hunting.

In recent decades a range of personal audio devices have emerged, offering high quality, loud music. The technological achievements are impressive, and the continued miniaturization incl. amplifiers and transducers breaks boundaries constantly. Recent years mp3 players, such as the iPods are little wonders, which allow us to listen to high quality music at the scene of our choice. Unfortunately, also to exceedingly loud music for some.

This study was inspired by what appears to generally conservative conclusions in the literature, on the possible risk of damage from personal stereo systems (PSSs). One aspect relates to the methods for estimating the exposure levels of PSS users. When the sound is presented by earphones, e.g. inserted in the ear, the standardized methods for measurement and assessment of the noise exposure were inapplicable, until the publication of the ISO 11904 series [3, 4]. Although several of the previous studies employed methods, which were in principle quite similar to the ones later laid down in the standards, the interpretation of the results may have been overly cautious. In the present paper, statements from previous studies have been considered with a view to the now internationally accepted method for determining noise immission from source close to the ears. The present study was first presented in [5].

## 2. FREE- AND DIFFUSE-FIELD RELATED LEVELS

The sound exposure from PSSs and similar, can only be measured either by miniature microphones in the ears of the subject, or by a manikin with built-in microphones. This can–in principle–give an accurate measure of the exact ear exposure, but our hard-earned experience about risk levels relate to sound fields propagating in open spaces, and not the levels in the ear of the exposed person. The levels measured at the ear can therefore not be directly compared to traditional levels. Instead, free-field related sound pressure levels, $L_{FF}$ may be estimated from the sound pressure levels measured at the ear, $L_{ear}$ by subtraction of the free-field-front head-related transfer function (in dB) $L_{FF} = L_{ear} - \Delta L_{FF}$. The diffuse-field related sound pressure level may be estimated in a similar way, and there are arguments in favor of using either one of these. Much of the current knowledge of hearing and specifications to weighting functions are found with free-field frontal sound incidence, but most of the experience with noise exposures and hearing damages are presumably from situations with near diffuse-field properties.[1]

The ISO 11904 series describe how free- and diffuse levels can be derived from ear measurements, either in human ears (the *m*icrophone *i*n *r*eal *e*ars technique, MIRE technique) [3] or by a manikin (the manikin-technique) [4]. With the MIRE-technique measurements may be made either at the eardrum or at the ear canal entrance, either open or blocked. The HRTF can either be determined for the individuals, or taken from tabled data in the ISO 11904-1. With the manikin technique, the HRTF shall be taken from a table in ISO 11904-2. The methods are assessed in [6].

The free- and diffuse field related levels may be subjected to A-weighting, etc., and used for estimation of exposure levels in ways similar to traditional methods. Exposure levels are normally estimated from a time-weighted average, where an equal exposure is achieved in half of the time with every 3 dB increase in level (and with a limit of 85 dB A-weighted for 8 hours), which corresponds to (e.g. [7]):

$$L_{EX} = L_{FF} + 10 \cdot log_{10}\left(\frac{T[min]}{480}\right) \tag{1}$$

when, e.g., estimated from free-field related levels.

## 3. EXPOSURE LEVELS

Clark [8] reviewed the studies available at the time, concerning the use of personal stereo systems [9, 10, 11, 12, 13, 14, 15]. He concluded that: *"In summary, there seems to be a consensus that PSSs are capable of producing hazardous sound levels to the ear, that if used at maximum levels for prolonged periods pose a risk of causing NIHL. However, a number of studies that evaluated preferred listening levels and frequency of use indicate that concern is warranted for only those few listeners who prefer listening at maximum levels for extended periods of time."* He was seconded by a contemporary study (Turunen-Rise et al. [16], reviewing some of the same sources and [17, 18]): *"... the risk of acquiring permanent noise-induced hearing loss (NIHL) from use of PCP* [personal cassette players] *is very small for what we found to be normal listening conditions".*

The methods employed in the different studies at that time were quite diverse. In some studies the sound was measured in a standardized coupler and directly compared to limits applicable for traditional methods (free-field methods). It is reasonable to believe that this leads to an overestimation of the exposure levels, a factor which could have contributed to the conservative conclusions. But a few studies employed techniques in principle comparable to those now internationally standardized, leading to free-field related sound pressure levels. One of the first to

[1] The consideration of free-field versus diffuse-field must not be confused with free-field versus diffuse-field calibration of microphones. These types of microphones are constructed in such way that their pressure sensitivity at high frequencies compensates for the microphone's impact on the given sound field. The microphone thereby estimate the sound pressure of the un-obstructed sound field, as long as the sound field is, respectively, a free field with normal incidence at the microphone or a diffuse field. The magnitude of difference in frequency response for a free-field versus diffuse-field calibrated microphone is many times smaller than the difference between a free-field-front HRTF and a diffuse-field HRTF.

describe the method may well be Rice [19], which in a parallel study [15] (incl. 750 PCP users) concluded the following: *"These results suggest that about 5% of the sample are actually exposed to unobstructed field levels greater than an $L_{EX}$ of 90 dB. The conclusions may therefore be drawn that there is in fact a slight risk involved with listening through headphones to sound from PCP devices, the governing factors being the combination of sound level and listening time."*

The specific study thus concluded on the percentage of the user population, which exceeded exposure levels above 90 dB. Yet the almost universal limit of 85 dB is considered sufficient to only protect 85%-90% of the population from sustaining a material impairment after decades of industrial exposure (e.g. [20]). The percentage of listeners from Rice et al. [15] exceeding this limit is approximately 20% (estimated from the cumulative distribution).

The population of listeners in [15] were also interviewed about other effects, and it is concluded: *"About 20% of over 750 PCP users have reported symptoms of tinnitus or dullness of hearing after using their devices, which indicate that some potential of risk is present."* These conclusions are in somewhat contradiction to the conclusions of the reviews.

In one of the most recent studies (Williams [21]) measurements according to ISO 11904-2 were made for 55 adults, of which 25% exceeded an exposure level of 85 dB. It is concluded: *"While some individuals do expose themselves to significant risk of noise injury by using earphone levels at high settings, the data collected in this study does not indicate that for the majority of typical users there is a significantly increased risk of hearing loss due to PSP* [personal stereo players] *use alone."* This is a somewhat conservative general conclusion to the study, and it is added: *"However, there is a definite need for an education/information programme for the 25% of the user population that falls above the level of risk deemed acceptable by work place regulations."*

## 4. USER HABITS

Some twenty years later, we see no cassette players and less CD walkmans. They have been replaced by much more universal music players. These players are much smaller, but can also produce very high levels of sound (100–120 dB, e.g. Fligor and Cox [22]). The price is so low that they are common devices for adolescents and children. This means that the user population is different from earlier PCP users. The user habits will also be specific for such population groups, and the minimal size and versatility enables a wider use.

One particular alarming habit of use is the listening to music in noisy surroundings, e.g. subways and trains. When the background noise is high, the volume is turned up. The effect of this was studied by Airo [1] (using methods comparable to ISO 11904-1), who concluded: *"The music level was on average set to exceed 85 dB when the background noise level was 72 dB. Some hearing loss risk would be expected when PCPs are used in noisy conditions at work or among traffic."* 15% of the test subjects exceeded the 85 dB exposure level.

Another alarming factor is the younger user population. This was studied by Ising et al. [23], according [24]: *"Are the listening habits of the younger generation potentially dangerous to hearing? Ising et al. studied 681 students aged 10 to 19 years [23]. Although 50% of students listened to music for less than one hour per day, 10% listened for four or more hours. Among those aged 12 to 16 years, 10% chose to set the listening level at 110 dB(A). It was estimated that 7% were exposed to noise levels likely to damage the cochlea. They recommend that the sound levels for portable music players be limited to 90 dB(A)"*. This suggestion has to our knowledge not yet been followed (although headphones with limiters have been put on the market for professional use by Sennheiser).

## 5. POSSIBLE EFFECTS

The assessment of possible effects is as ever complicated, since the effect from exposure of the PSSs can rarely be singled out. Most assessments have been carried out as part of national health protection programs, where the primary objective have been to assess the effects of the noise from the working place. The possible effect from PSSs

have–if anything–been a side-effect, and the PSS user population a subset of the users. The assessment of children and adolescents is not systematic. The typical course of hearing tests for a child is to establish disorders by birth (or in early years), and if the child is considered normal, the hearing will only be occasionally monitored during school ages with methods, which are too crude to detect the subtle changes due to excessive sound exposures. Scattered reports about adolescents with severe NIHL from the use of PSSs, does however exist (e.g. Fligor [25]).

One larger-scale study has examined the state of hearing for a population incl. personal stereo (PS) users (LePage and Murray [2]). The state of hearing was assessed by measurement of transient evoked otoacoustic emissions (TEOAE). Otoacoustic emissions (OAEs) are known to relate to the functions of the outer hair cells, and are thus considered to reflect the state of the most vulnerable part of the hearing organ. What must be considered a clear effect of both industrial noise and PS use was demonstrated, and it was concluded [2]: *"...the young adult PS users (20–29-years) had otoacoustic emission strengths significantly lower than non-users ($P < 0.001$), suggesting that the decline occurs in the late-teenage and early-adult period – a decade earlier than the expected industrial effect."*

## 6. CONCLUSIONS

There seem to be consensus across studies that PSSs are used in ways, which leads to exposure levels above risk levels for a part of the user population (15%–25%). This may be a limited number of individuals in absolute terms, but PSSs are used by an expanding population group, and by younger and younger individuals. The risk factor for children and adolescents is not well known, since we (generally) base risk assessments on the hard-earned experience from noise-induced hearing losses from adult industrial workers.

## 7. ACKNOWLEDGEMENTS

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