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Musicians and the Prevention of Hearing Loss

Marshall Chasin, AuD[1]

[1] *Musicians' Clinics of Canada, Toronto, Ontario, Canada*

Correspondence should be addressed to Marshall.Chasin@rogers.com

ABSTRACT

Music exposure can pose a problem, especially with the advent of "portable" music. Despite the complexity of the human auditory system, it does not know the difference between industrial noise and music. Indeed, many of the factors can equally affect music exposure as well as industrial exposure. This talk is an overview of those factors affecting hearing for musicians as well as environmental strategies and hearing protection to minimize the potential damaging effects of music.

1 Summary

Hearing loss is frequently referred to as the invisible handicap. Unlike many of the other injuries in the performing arts field, hearing loss is slow and gradual, without pain that may only manifest itself after many years of music exposure. It is generally the family and friends who may notice the hearing loss long before the musician may notice it. The need for hearing loss prevention is something that has only become explicitly realized by musicians over the last generation.

Historically there is a larger body of literature concerning the effects of noise on hearing than the effects of music. Many of these historical studies are directly applicable, while others less so. In the realm of noise exposure there have been laboratory studies that examine the effects of permanent hearing loss (also known as Permanent Threshold Shift or PTS) in mammals such as the chinchilla and guinea pig as well as studies on the effects of humans using a Temporary Threshold Shift (TTS) paradigm. In a TTS paradigm a worker's hearing status is measured prior to an exposure and then immediately after- the difference being a measure of TTS in decibels (dB). Between 1968 and 1973 there were a number of large scale surveys resulting in models of hearing loss for industrial workers who have been exposed to noise from industry. These large scale surveys (PasschierVermeer, 1986, 1971; Robinson, 1968, 1971; Baughn, 1973; Lempert & Henderson, 1973) have served as the bases for many policies in various jurisdictions, most being applicable to musicians as well as industrial workers. These large scale studies have served as the bases for the policies of the EPA (1973), NIOSH (1973, 1998), OSHA (1983), and finally the ISO R1999 (1990) model of hearing loss that is commonly used internationally.

2 Permanent Threshold Shift (PTS) in musicians and industrial workers

As the name suggests, PTS is the permanent loss of sensitivity to certain sounds as a result of exposure to noise and/or music. The vast majority of cases concern a long term exposure which has the effect of damaging cochlear hair cells resulting in apoptosis or cell death. In some rare cases, single traumatic insults such as an explosion or a feedback squeal can also cause PTS but the pathophysiology is less welldefined, most likely being related to a combination of apoptosis, necrosis and a mechanical breakage of some of the inner ear structures.

These large scale studies demonstrated that there was minimal measureable PTS for hearing exposures less than 85 dBA (dB A-weighted) for exposures of 8 hours a day for 40 years. The use of these models and large scale studies, while applicable to groups of industrial workers and for policy decisions, they are less applicable to music and groups of musicians, Musicians do not expose themselves for 40 hours each week, nor should policy "merely" be to compensate a musician once they have retired. Hearing loss prevention is required.

2.1 The 3 dB and 5 dB Exchange Rate

In 1966 the Committee on Hearing and Bioacoustics (CHABA) attempted to develop a model that would relate exposure level to duration of exposure in an attempt to develop Damage Risk Contours (DRC). For example, can we relate an exposure of 85 dB for 20 hours a week to the potential risk for someone who is exposed to 90 dB for 18 hours a week? Such a relationship is called an "exchange rate" or "trading relationship".

The 3 dB exchange rate is based on the "equal energy hypothesis" that the effects of noise (or music) exposure that is summed over time adds up to a well-defined exposure energy that is independent of being steady state or intermittent. In this scenario, an exposure to 90 dBA for 40 hours a week is identical to 93 dBA for 20 hours a week (…96 dBA for 10 hours a week, 99 dBA for 5 hours a week, and so on). This "3 dB exchange rate" is the policy of NIOSH (1973, 1998) in the United States and most other jurisdictions around the world (Suter, 2007).

The 5 dB exchange rate is predicated on the assumption that equal amounts of temporary threshold shift (TTS) are equally damaging. In this scenario, an exposure of 90 dBA for 40 hours a week is identical to 95 dBA for 20 hours a week (… 100 dBA for 10 hours a week, 105 dBA for 5 hours a week, and so on). There is very little theoretical research to support this view since PTS is not correlated to TTS. Subsequently this "5 dB exchange rate" is not found commonly in policies around the world but the Occupational Safety and Health Administration (OSHA, 1973) in the United States and a few jurisdictions in Canada do subscribe to this view.

Embleton (1995), in reporting on results of an International Institute of Noise Control Engineering Working Party paper, concluded that "the scientific evidence is that 3 dB is probably the most reasonable exchange rate for daily noise exposure. Statistically it is also a good approximation for the results of many epidemiological studies relating to intermittent exposures, even though these show considerable spread about any mean curve". (p. 18).

2.2 Music and Dose

A result that stems from the use of exchange rates is that there is a "maximum dose" that can be measured such as "100% dose of music exposure". If one assumes that an exposure of 85 dBA for 40 hours each week is "100% dose" then 88 dBA (85 dBA + 3 dB) for 40 hours each week would be "200% dose" and 85 dBA for only 20 hours each week would be "50% dose". This above dose-calculation assumes a 3 dB exchange rate. If the dose calculation would have used the 5 dB exchange rate, then the 88 dBA exposure for 40 hours each week would have been closer to a 150% dosage.

The result of research into the effects of noise (and music) demonstrate that it is not just the sound level (in dBA) but the sound level over a period of time that can potentially damage one's hearing. There is nothing wrong with going to a rock concert on Friday night as long as you don't mow your lawn on Saturday. It is the dose that we try to keep below "100%".

There are many commercially available dosimeters that can be used (where a light may flash red when 100% dose is achieved) and recently some Smartphone (OS) based dosimeters have become available.

3 Temporary Threshold Shift (TTS)

As the name suggests, TTS is a temporary loss in sensitivity to certain sounds for a period following an exposure to noise or music. The pathophysiology is not well understood but appears to be in part related to the temporary disarticulation between the outer hair cells and the tectorial membrane in the cochlea (which re-establishes itself after 16-18 hours) and glutamate levels that become ototoxic, where the levels return to a normal (lower) level after 16-18 hours. This may be noted by the individual as a feeling of fullness or numbness after a loud event with or without tinnitus. The tinnitus may continue for several days after the event. TTS, being a "threshold" change, assesses cochlear pathology and indeed other measures of cochlear function such as Otoacoustic Emission (OAE) testing would also show a temporary reduction in cochlear sensory function for a period after an exposure to noise or music. The occurrence of TTS is considered to be a cochlear sensory (rather than a neural) phenomenon.

TTS has to be discussed in two time periods. Prior to the year 2000 TTS was considered to be a benign feature of exposure to noise or music resolving in 16-18 hours- a temporary cochlear phenomenon. Because TTS was "temporary" it was a paradigm commonly used to assess whether a person was subjected to an overly high level of noise or music. Academic Institutional Research Review Boards (IRB) had little concern with approving such studies. Much of the research revolved around whether a measure of TTS could be used to predict future PTS, however no research has shown that TTS (or the pattern of recovery from TTS) can be used as a predictor of future PTS.

After the year 2000, a number of studies have demonstrated that despite hearing thresholds returning to the pre-exposure level (i.e., no measureable TTS), there can be some permanent neural deficits that may not be immediately detectable. That is, despite a return to normal cochlear function (with a normal audiogram), there can be neural deficits that remain. Specifically, the synapse from the cochlear inner hair cells to the VIII auditory nerve can be permanently altered with a reduced amplitude on the Wave I on a traditional ABR evoked audiometry paradigm. This has been referred to as "cochlear synaptopathy" (Kujawa & Liberman, 2009; Kujawa, 2014; Kujawa & Liberman, 2015; Liberman & Kujawa, 2017).

While prevalence estimates of cochlear synaptopathy in animal models are found in the literature, it may be erroneous to relate this to humans. There is very little data but there has been some research on human temporal bones. Viana et al. (2015) counted the number of synapses in five human temporal bones. As a function of age, there were fewer synaptic connections at the time of death. Another study by Makary et al. (2011) demonstrated that again, as a function of age in 100 human temporal bones, there was a marked decrease in cochlear spiral ganglion cells, despite having intact cochlear sensory cell populations at the time of death.

Cochlear synaptopathy has colloquially been referred to in the media as "hidden hearing loss" and while that can grab headlines, at this point in time, little is known about how this can manifest itself in humans, how this can be reliably measured, and what the prevalence in humans actually is.

4 Music and Noise

In a strictly physical sense, music is noise. Both music and noise have many features in common. They are both time-varying sources of vibration in air that have peaks and valleys in their amplitudes. Both music and noise can be "intermittent" or "steady state". Occupational noise can have sustained levels in excess of 100 dBA and many forms of music can have sustained levels in excess of 100 dBA. Having said this, industrial noise sources tend to have more energy in the lower frequency regions whereas music can have significant mid and high frequency energy, although even this gross generalization can be simplistic. And the audiometric configuration of long-term noise exposure is even similar to that of long-term music exposure. It is frequently difficult to differentiate a noise induced hearing loss from a music induced hearing loss purely on audiometric data. A thorough case history is required as the differentiating element. (Behar, Chasin & Cheesman, 1999; Chasin, 1996, 2009). It is therefore not surprising that many of the research results using noise as a stimulus can apply (or have been applied) to music in many national and international regulations and policies.

5 Music sound levels

Because of the physics of musical instruments, room acoustics, and even electronic sound re-enforcement, music can be played at a number of different levels. Table I, adapted from Chasin (2006), shows typical sound levels in dBA from over 1000 musicians measured at a distance of 3 meters when music is played at an "average" or mezzo forte level. The top and bottom quartiles were removed from these data. In the vast majority of instruments (except for acoustic piano and singing), sound levels far exceeded 85 dBA. These data are from solo performances. In real life performances of bands or orchestras, the overall levels would be much greater.

Musical Instrument at 3 meters	**Sound Level (dBA)**
Normal piano practice	60-90
Cello	80-104
Flute	98-114
Trumpet	88-108
Amplified guitar	105-112
Vocalist	70-85
Saxophone	75-110

Table I: Based on over 1000 musicians, measured from 3 meters, typical "average" sound ranges of a selection of musical instruments. Adapted from Chasin (2006) with permission.

There are commercially available dedicated sound level meters that can be used to measure the sound level. There are also many Smartphone apps that are available on both the OS and Android platforms that can perform this function as well. While there are limitations with many of these Smartphone apps, they can be accurate for mid-level sounds

6 Hearing Protection

Because of the laws of physics where high frequency sounds acoustically "see" any obstruction better than lower frequencies, conventional industrial hearing protection tends to provide only about 20-25 dB of protection for the lower frequency sounds but up to 35-40 dB for the higher frequency sounds. Because sound energy can enter the skull directly to the cochlea (in the 2000 Hz region), the maximum limit of attenuation on any hearing protector is 40 dB. (Berger, 1986).

Musicians' earplugs utilize an acoustic network (either Helmholtz or wavelength based) to re-establish much of the mid and high frequency sound energy; the result being a flat or uniform hearing protector. Having a uniform attenuation hearing protector allows the musician to hear the proper balance between the lower frequency fundamental (or tonic) energy and the higher frequency harmonic energy. Acoustic energy in the music is reduced identically from a potentially damaging to a nondamaging sound level. Various manufactures of the Musicians' earplugs have different strategies to accomplish this but most provide approximately 15 dB of sound attenuation. While 15 dB does not sound like a lot, every 3 dB reduction effectively cuts the dose of exposure in half. A musician wearing a 15 dB uniform hearing protector can then be in a musical environment for 32 times as long as without hearing protection- more is not necessarily better.

7 And some other strategies

There are a number of other strategies, both environmental and behavioral, that can serve to reduce the overall dose that a musician may obtain from their exposure. These include altering the direction and distance from higher level noise sources as well as moderation. A full discussion of these can be found in Chasin (1996) and Chasin (2009).

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