

# 1 Hearing Loss Prevention for Musicians and Introduction to the Problem

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## INDUSTRIAL NOISE AND MUSIC

Music and industrial noise have many similarities and some interesting differences. Depending on the musical instrument, the spectral shape and concentration of energy can be quite similar to those of an industrial noise spectrum. This is true of stringed, vocal, brass, and woodwind instruments. It is not true, however, of percussive instruments such as the drums or cymbals—this spectrum is more consistent with the noise spectra found in stamping plants where the sudden percussive sounds yield a broadband spectrum with significant high frequency energy components. However, most industrial noise spectra have their spectral energy based in the lower frequency range with very little energy above 1500 Hz. In contrast, many forms of music can have a broadband spectrum where the higher frequency harmonic structure can be more intense than the lower frequency fundamental energy. Because of this spectral difference, the nature of the hearing loss resulting from the music exposure

can be subtly different from exposure to an equivalent intensity noise spectrum. This however, is not always the case, and it is not uncommon to find that a music spectrum and an industrial noise spectrum have similar shapes and intensities. In many cases, only the client history can provide clues to the etiology of the hearing loss.

There can also be substantial intensity differences both in terms of the overall intensities and the dynamic ranges (difference between the most and least intense components). Instrumental music has a dynamic range on the order of 100 dB with brush sounds on the drum typically being the least intense and amplified and percussive music being the most intense. Using modern hearing aid terminology, instrumental music can have a modulation depth of 100 dB (and a modulation rate of up to 100 Hz)—meaning the dynamic range can be around 100 dB and it can vary in intensity up to 100 times per second. Vocal music can have modulation rates around 2 to 10 Hz with the bulk of the singing being between 4 and 6 Hz. (Chung, 2004). In contrast, industrial noise (and most noise sources) has a very low

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modulation rate (<2 Hz) and an almost nonexistent modulation depth (i.e., very little intensity difference between the most intense and least intense noise components). Industrial noise however can have more sustained high intensity periods than are typically found with music. Music tends to have greater dynamics with short periods of relative quiet followed by periods of greater intensity.

### KEY POINT

Differences between music and noise are more in the realm of intensity dynamic ranges and in the temporal characteristics rather than the spectral shape or peak intensity measures.

The differences between music and noise are therefore more in the realm of intensity dynamic ranges and in the temporal characteristics rather than the spectral shape or peak intensity measures. Wagner's "Ring Cycle" (Camp & Horstman, 1992) has levels similar to the most intense industrial environments, and many forms of jazz and folk music have levels similar to that of a busy, but quiet, office environment. Table 1-1, adapted from Camp and Horstman (1992, based on what is considered to be the most intense classical music), shows intensities for some instruments during the most intense movement ("Götterdämmerung").

Table 1-2 (adapted from Chasin, 2006) shows measurements of a wide range of musical instruments measured in the horizontal plane at a distance of 3 meters. All measurements were performed in a typical musical environment for that particular instrument and are measured in dBA.

**Table 1-1.** Measurements of peak SPL taken during the most intense movement of the Wagner's Ring Cycle, considered to be the most intense piece of classical music.

<i>Instrument</i>	<i>Peak Levels (dB SPL)</i>
French horn	107
Bassoon	102
Trombone	108
Tuba	110
Trumpet	111
Violin	109
Clarinet	108
Percussion	>120

*Note.* Adapted from "Musician Sound Exposure during Performance of Wagner's 'Ring Cycle,'" by J. E. Camp and S. W. Horstman, 1992, *Medical Problems of Performing Artists*, 7(2), pp. 37-39. Adapted with permission.

## FACTORS AFFECTING HEARING LOSS

### PTS and TTS

Understandably, many of the seminal studies on the effects of noise exposure (and by extension, music exposure) are either based on animal models where a permanent threshold shift (PTS) has been created, or on humans in well-controlled laboratory-based experiments where a temporary threshold shift (TTS) has been created. As the name suggests, TTS typically resolves within 16 to 18 hours, but tinnitus may last several days. TTS, like PTS, typically occurs one half octave above the offending stimulus frequency,

**Table 1-2.** Unless otherwise specified (e.g., “near left ear”), all measurements were taken at 3 meters for a large number of musicians (inner two quartiles) using differing styles of playing and different instruments.

<i>Musical instruments at 3 meters (at 0° azimuth)</i>	<i>dBA</i>
Normal piano practice	60–90
Loud piano practice	70–105
Keyboards (electric)	60–110
Vocalist	70–85
Chamber music (classical)	70–92
Violin/viola (near left ear)	85–105
Violin/viola	80–90
Cello	80–104
Acoustic bass	70–94
Clarinet	68–82
Oboe	74–102
Saxophone	75–110
Flute (near right ear)	98–114
Flute	92–105
Piccolo (near right ear)	102–118
Piccolo	96–112 <sup>1</sup>
French horn	92–104
Trombone	90–106
Trumpet	88–108
Tympani and bass drum	74–94
Percussion (at left ear near high hat)	68–94; peak 125 dB SPL
Amplified guitar (using in-ear monitoring)	100–106
Amplified guitar (using wedge loudspeaker monitoring)	105–112
Symphonic music	86–102
Amplified rock music	102–108
MP-3 player (volume 6/10)	94
MP-3 player (full-on volume)	105

<sup>1</sup>With a peak level of 126 dB SPL, piccolo players are banned from my office!

*Note.* From “How Loud Is that Musical Instrument?” by M Chasin, 2006, *Hearing Review*, 13(3), p. 26. Used with permission.

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and in the unprotected ear the offending frequency is near the natural ear outer canal resonance, which is between 2700 and 3000. TTS and PTS therefore manifest themselves first in the 3000 to 6000 Hz region, although it is not unusual to find a “noise notch” in the audiogram up to 8000 Hz (especially for violins and piccolo players). Mills et al. (1983) found that for very low frequency stimuli (below 500 Hz), the TTS would be in the 300 to 750 Hz region, regardless of the exact stimulus frequency.

In the mid-1960s the Committee on Hearing and Bioacoustics (CHABA) tried to establish a predictive relationship between TTS and PTS. They argued that “If any single band exceeds the damage-risk contour specified, the noise can be considered as potentially unsafe” (Kryter, Ward, Miller, & Eldredge, 1966). This research led to the development of a series of damage risk criteria (DRC). If the measured noise levels did not achieve the DRC contour, then it was not damaging. At that time, several assumptions

were made: (a) regular “quiet periods” would reduce the risk, and (b) recovery from TTS was only related to the magnitude of the stimulus.

The CHABA report discusses the “on fraction rule” as a rule that “. . . predicts that when the noise is on for half of the total period of exposure, the amount of TTS would be one-half of that which would have been predicted if the noise had been continuous” (Melnick, 1991, p. 150). That is, damage can be mitigated by intermittency. Melnick (1991) also showed that the recovery from TTS was related to both the magnitude and the duration of the exposure.

A decade later, Dixon Ward (Ward, Cushing, & Burns, 1976), who was one of the architects of the CHABA report, developed upper limits of “effective quiet”—levels that would produce no TTS—and these were significantly less than those stated by CHABA. The quiet periods would serve to reduce the amount of predicted damage. The estimates of effective quiet are given in Table 1-3,

**Table 1-3.** Estimates of “effective quiet” (Ward, Cushing, & Burns., 1976) and a comparison of levels from the location in a classical orchestra of three instrument sections while they were not playing.

<i>Frequency (Hz)</i>	<i>Effective Quiet (dB SPL)</i>	<i>Clarinet (dB SPL)</i>	<i>Violin (dB SPL)</i>	<i>Trumpet (dB SPL)</i>
250	77	72–82	75–84	75–98
500	76	73–84	75–87	76–98
1000	69	69–81	71–78	70–87
2000	68	66–74	70–74	66–77
4000	65	56–62	59–65	60–67
Broadband	76 dBA			

*Note.* From *Musicians and the Prevention of Hearing Loss* (1st ed., p. 27), by M. Chasin, 1996, Clifton Park, NY: Delmar Learning. Reprinted with permission of Delmar Learning, a division of Thomson Learning.

along with intensity ranges measured in three classical instrument sections while the musicians were *not* playing. Note that all three instrument groups exceeded the effective quiet levels even when not playing. It should be noted that these are not *critical levels*, which are octave band levels that would cause 5 dB of TTS after 16 hours of exposure. Once corrected for the difference in definition, the Ward et al. (1976) data are consistent with the later work of Mills et al. (1979), which uses critical levels.

high levels of glutamate brought about by high levels of noise, this substance can become ototoxic and cause the post-synaptic cells to swell. This is thought to be a temporary condition. Using a glutamate blocker will minimize TTS in some experimental situations.

#### KEY POINT

The relationship between PTS and TTS are not well defined, but TTS is a necessary precursor to PTS.

### PTS and TTS Revisited

While it would be tempting to conclude that someone who is very susceptible to TTS in a well-controlled study would also be someone who is more susceptible to PTS, there is no evidence to support this. At most, one could say that TTS is a necessary precursor to PTS. One of the reasons is that PTS and TTS may have different physiological mechanisms.

Henderson et al. (2006) argued that there are two possible mechanisms of TTS and that these are probably not identical to those of PTS (cell death due to necrosis or apoptosis), although there may be some overlap. When TTS occurs, the tips of the outer hair cells can become disconnected from the tectorial membrane and result in a hearing loss. However, there is a period of time that the hair cells can become reconnected to the tectorial membrane, thereby re-establishing the previous hearing levels. This is the most probable explanation for TTS. TTS may also be brought about by glutamate ototoxicity. Glutamate is an excitatory neurotransmitter substance that occurs in the synapse between the inner hair cells and the VIII auditory nerve. With

### PTS AND MODELS

Between 1968 and 1973 there were a number of large scale field studies relating to the relationship between noise exposure and PTS. (Baughn, 1973; Lempert & Henderson, 1973; Passchier-Vermeer, 1968, 1971; Robinson, 1968, 1971). The Passchier-Vermeer, Robinson, and Baughn studies served as the basis of the 1973 United States Environmental Protection Agency's (EPA) Criteria Document. These studies noted very little PTS for long-term exposure (40 years) to 8-hour work day exposures of 85 dBA or less, averaged at 500 Hz, 1000 Hz, and 2000 Hz. There was poor predictive ability for 3000 Hz and 4000 Hz hearing acuity. The Lempert and Henderson (1973) study formed the basis of the National Institute for Occupational Safety and Health (NIOSH) model. A more recent model is the one developed by the International Organization for Standardization (ISO) R-1999 (1990), which, for the most part, is consistent with previous models and is "... sufficiently accurate to support the needs of most regulators, administrators, and others who

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**Table 1-4.** Five models with predicted PTS at three exposure levels. Note that exposure levels of 85 dBA will still result in some PTS.

	<i>Passchier-Vermeer</i>	<i>Robinson</i>	<i>Baughn</i>	<i>NIOSH</i>	<i>ISO R-1999</i>
85 dBA	8	6	9	5	6
90 dBA	15	12	14	11	11
95 dBA	23	18	17	20	21

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need rough predictions on the effects of noise on groups of workers” (Johnson, 1991, p. 174). Table 1–4 compares the predicted PTS at 4000 Hz for three exposure levels, in five models. Exposure levels as quiet as 85 dBA are predicted to still cause a small, but measurable, PTS.

### EXCHANGE RATES

The CHABA DRCs specify contours of equal risk for PTS given a specified exposure level *and* exposure time. The relationship between exposure level and time exposed is called the exchange rate. A 3 dB exchange rate (or 3 dB-rule) means that the exposure is identical if a person is exposed at a level 3 dB more intense but for half the time. That is, there is a *trade-off* or *exchange* between intensity and duration. A 5 dB exchange rate, for example, would mean that a 90 dBA exposure for 40 hours a week is equivalent to a 95 dBA exposure for only 20 hours. Correspondences can be derived using simple algebra—85 dBA for 40 hours a week = 88 dBA for 20 hours a week = 91 dBA for 10 hours a week, and so on.

This relationship appears to be valid for exposures up to about 115 dBA. There is a paucity of data to support such a relationship above this point.

Although there has been some historical debate about whether the 3 dB or the 5 dB exchange rate is most appropriate, Embleton (1995) concluded that “the scientific evidence is that 3 dB is probably the most reasonable exchange rate for daily noise exposure” (p. 18). It should be noted that “exchange rates” are only meant to summarize the data. Ward (1982) stated that the effects of noise exposure are caused by dosage, not merely sound level. Some jurisdictions around the world still use the 5 dB exchange rate, but there is no science supporting this decision. Further discussion on DRCs and exchange rates can be found in Chapter 6.

### KEY POINT

Although there has been some historical debate about whether the 3 dB or the 5 dB exchange rate is most appropriate, most of the evidence points to the 3 dB exchange rate.

## AUDIOMETRIC ASYMMETRIES

A hallmark of industrial noise exposure is a symmetrical hearing loss on the audiogram (with a “typical” noise notch in the 3000 Hz–6000 Hz region; Alberti, 1982). The two reasons for this symmetry are that (a) most industrial noise is concentrated in the lower frequency region and (b) industrial workers frequently find themselves in reverberant environments. Because low frequency sounds have long wavelengths, the head and body do not represent a shadow for the noise. A noise source emanating from the right side of the worker can be just as intense at the left ear as the right ear. This is exacerbated by the environmental reverberation, where reflected noise bounces off walls and other obstructions with minimal loss of energy. The result is the sound field on one side of the head is similar to that on the other side regardless of where the noise initially emanated from.

### KEY POINT

Because of the significant higher frequency energy content of music, coupled with performing and listening in relatively nonreverberant environments, audiometric asymmetries may be found.

In contrast, music has significant mid- and high frequency energy components and is typically played or heard in relatively nonreverberant environments. The shorter wavelengths found in the treble notes undergo significant attenuation from one side of the body to the other—

head and body baffle effects. And with the relative lack of reverberation, reflected echoes are of lower intensity. A violinist who holds his instrument near the left ear will receive a much higher sound level at the left ear than the right ear for the above reasons. Slight audiometric asymmetries are therefore frequently found. These asymmetries may amount to up to 25 dB (e.g., a drummer with the high-hat cymbal near the left ear), but larger asymmetries are not typical of music exposure and should be investigated in order to rule out retrocochlear pathologies. Depending on one’s clinical protocols, all asymmetries should be investigated, even though some of them may be explained in terms of head shadow and body baffle effects.

## SUMMARY

The differences between music and noise are more in the realm of intensity dynamic ranges and in the temporal characteristics rather than the spectral shape or peak intensity measures. In many instances music has significantly more high frequency energy content, but this is not always the case. It is this high frequency energy content (coupled with a relatively nonreverberant environment) that can result in audiometric asymmetries with musicians.

In 1966, the Committee on Hearing and Bioacoustics (CHABA) tried to establish a predictive relationship between TTS and PTS. These resulted in damage risk criteria (DRC), but despite the common use of these “equal exposure” contours, they are based on some questionable assumptions. PTS and TTS are not always correlated, and the most that can be said

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is that one cannot have PTS from long-term noise or music exposure without first having TTS. This may be related, in part, to differing mechanisms underlying PTS and TTS.

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**Acknowledgement.** Some of the material used in this chapter was adapted with permission from *Musicians and the Prevention of Hearing Loss* (1st ed.), by M. Chasin, 1996, published by Delmar Learning, a division of Thomson Learning.

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