Potential Risk of Hearing Damage Associated with Exposure to Highly Amplified Music

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Abstract
The experience of highly amplified music listening is described from a psychoacoustic and phenomenologic standpoint in order to characterize both the estimated risk of hearing damage and the perception of such a risk. Exposure as attenders and as the result of a professional activity are examined separately. Data collected in discotheques are analyzed, showing that this type of music is characterized by (a) strong pulsations, the rate of which is approximately 2 Hz; (b) a narrow dynamic range; and (c) a sloping spectrum with maximum energy in the 1/3-octave centered at 63 Hz. This spectrum is almost parallel to the free-field hearing threshold curve raised by 80 dB. Although temporary threshold shift is predictable for different durations of exposure to this type of sound, the long-term risk of permanent threshold shift appears to be very slight for those who are regularly exposed to loud music. An anthropologic approach is proposed with a health education approach to the prevention of hearing loss resulting from amplified music listening.

Key Words: Amplified music, hearing loss, leisure noise, prevention

Listening to music at high sound levels is now a facet of life in industrialized countries. Strong amplification of music originated in the sixties when rock concerts were attended by very large groups of people. This gave rise to a new way of listening to music that was later encouraged by the commercialization of increasingly powerful sound reproduction. Exposure to loud music has been a matter of concern among hearing specialists since the outset; however, there is little evidence that expression of these concerns has had any influence on such a significant cultural trend. Opportunities to listen to loud music have been increasing steadily, and now are systematically associated with a variety of social activities.

Home stereo equipment is often the cause of complaints between neighbors. Loudspeakers installed in cars can generate sound levels higher than 100 dBA. Powerful personal radio, cassette, or disc players can generate equivalent diffuse-field sound pressure levels of up to 100 dBA (Medical Research Council, 1986). This means that people can expose themselves to loud music in almost any environment, and seem to systematically associate this kind of exposure with a variety of daily activities. Even physical fitness training is associated with highly amplified music in an increasingly systematic way. Professional baseball players expose themselves to very loud music during training periods. The sound environment in meeting places such as bars and clubs is typically characterized by loud music. There is virtually no festivity, party, or wedding today without high-level background music.

In the following account, the experience of listening to highly amplified music is described from a psychoacoustic and phenomenologic standpoint in order to characterize both the estimated risk of hearing damage and the perception of such a risk.

Psychoacoustic Description of Highly Amplified Music Listening

The various conditions of highly amplified music exposure mentioned above share common spectro-temporal features, namely, high sound levels in the low-frequency range
maximizing beat perception. In order to characterize this type of sound, discotheques are often considered as the typical, if not referential, listening conditions. Music is being produced specifically for this type of setting. Sound technicians on those premises are responsible for setting sound reproduction systems according to definite standards or expectations, as defined below. Disc jockeys are also requested to further adjust the output level and the response curve of their systems with respect to actual attendance.

For the purpose of the present description, so-called “house” music was recorded at the center of the dance floor in three of the most well-attended discotheques in Montreal. Five 10-sec samples judged as being representative by the disc jockey were recorded in each discotheque at a time of day when no patrons were present. A Brüel-Kjaer (model 2231) sound level meter coupled to a Sony (PCM-1000) digital recorder was used. The samples were later assessed in the laboratory using a Brüel-Kjaer (model 2123) analyzer. This music sampling is obviously limited, and the related data are exploratory in nature. However, the high degree of similarity found in the spectral content of the music samples in the three discotheques visited, as shown below, suggests that these samples provide a valid representation of this type of amplified music exposure.

Figure 1 depicts the pressure-time envelope of a 1.5-sec sample of discotheque music. Two features of this sample are typical of such music: (a) the pressure fluctuations are systematically characterized by pulsations, the rate of which is approximately 2 Hz, that is, 120 beats per minute; and (b) the dynamic range is relatively narrow, the mean variation of the instantaneous pressure level being equal to or smaller than 10 dB. According to the three disc jockeys interviewed, the pulsating nature of this type of music is explicitly sought by those who create and reproduce it as well as by those who listen to it. The rate of 120 beats per minute characterizes most of today’s discotheque music, although, as mentioned by the disc jockeys interviewed, so-called brief “quiet” intervals are occasionally introduced during an evening, during which the rate is reduced to approximately 100 beats per minute (which was said to be typical of “rap” music). Interestingly, a rate of 120 beats per minute is compatible with the heart rate during moderately intense physical activity.

A recent laboratory experiment has shown that the tempo of rock and roll music has an accelerating effect on the heart beat of young adults pursuing intense physical exercise (Smith, 1987). Such data are preliminary in nature and, to our knowledge, have not yet been confirmed. Nevertheless, they suggest that the strongly pulsating character of highly amplified music does influence cardiac activity and, accordingly, the general level of arousal. It is plausible that listeners of highly amplified music seek such a psychophysiologic effect that, as discussed below, is further enhanced by proprioceptive rhythmic stimulation from the powerful low-frequency sounds.

From a psychoacoustic perspective, the spectral content of discotheque music presents several interesting features. Figure 2 depicts the average 1/3-octave band spectra of 8-sec representative samples of “house” music recorded in each of the three discotheques visited. The overall A-weighted sound levels were 101, 99, and 98 dB, respectively, for discotheques D1, D2, and D3.

The three spectra show four striking similarities:

1. Unweighted sound energy reaches a maximum in the 1/3-octave band centered at 63 Hz;
2. The band level steeply decreases below 63 Hz;
3. The band level shows a progressive decline above that frequency, to 3000 or 4000 Hz.

Figure 2 Average sound spectra of 8-sec representative samples of music recorded at the center of the dance floor of three discotheques. The overall A-weighted sound levels are 101, 99, and 98 dB in discotheques D1, D2, and D3, respectively.
4. A slight level increase is observed at higher frequencies, with a maximum at approximately 8000 or 10000 Hz.

The above characteristics of the spectral content of the music result from deliberate designs on the part of sound technicians and disc jockeys to adjust the output of the sound reproduction systems. Such deliberate designs are well illustrated by the following excerpts from interviews conducted with a sound technician and a disc jockey from D2. These excerpts represented the most explicit statements about the adjustment of the output of sound systems from the interview material collected.

Interviewer (MF): How do you adjust the discotheque's sound system?

Sound technician: The sound system is what's called a permanent type of installation for the discotheque. It's equalized for the dance hall, because dance music isn't the same thing as when you go to see a live performance. For a live performance, the sound has to be just about as flat as possible and you need to have the whole musical range possible, whereas in disco and dance music, it's not quite the same thing. Uh, it's a little more of a question of feeling. People like to feel the bass in their gut. And they have to be able to make themselves heard. So the mid-range between 1.6 and 4 k — we try to attenuate it a little more, so as not to interfere too much with people's voice range — and the high frequencies, for ... tempo, really.

If there's too much mid-range, like I said before, people have a hard time making themselves heard. They have to yell, so the ambient noise increases, and the DJ's going to want to turn up the volume because he can hear the conversation too much, and pretty soon it's a real tower of Babel.

Around where it starts to have a kick to it, between 125 and 80 cycles, we crank it up just a little to give the hit of bass that's there. We stay just about flat until 1.6; at 1.6 we drop it a little bit by about 2 or 3 dB depending on the resonance of the place, then we raise it again just a little bit starting at 10 k, to get the high-pitched "ts" (the hiss of the cymbals), to get a little more brilliant sound.

Disc jockey: Early on in the evening, I increase the bass frequencies and the high frequencies, and the mid-range... I have parameters on my console, so I set it at about 2 k, then I drop the system, you've got a lot of bass, you've got enough of the high frequencies, but you don't have much mid-range, so people's ears don't get tired, because that's what's most tiring.

Especially the bass — I think that the bass is what's just about the most important. If people don't have a good feeling on the floor — because between you and me, the mid and the bass, you don't have anything any more, and people are saying, "there's no more beat?" So, it's the bass... that's why we try to play not too much mid-range, so we don't blow people's ears out. When we play loud, we don't play much mid-range — the high frequencies aren't so bad... you hear them less, especially the way they're set up here — they go over people's heads. But the median frequencies bounce off everything... no matter where you are in the club, they bother you.

Interviewer: How do you know that it's a good sound level?

Sound technician: Through experience, I know when it's too loud — when I go to talk to someone somewhere in the club and I have to yell, it's too loud. Or when I hear the speaker rattle, it's a little too loud. It's a question of protecting the equipment, too ...

Disc jockey: I have a maximum that I can reach, but beyond that, it starts to distort — then it's going to be too loud, the amps will be overloaded at the insertion. So that's where you start to get distortion.

As we can see, the music spectrum design is governed by explicit purposes: (a) to maximize beat perception in the low frequency without introducing audible distortion; (b) to limit the sound level in the mid-range, thus allowing people to communicate verbally and averting complaints of annoyance due to excessive loudness; and (c) to emphasize the high frequencies in order to facilitate the perception of hissing sounds generated by the cymbals and other high-pitch percussion instruments that stress the beat.

Sound technicians also stated that they try to compensate the effect of the hall reverberation in trying to achieve the three purposes listed above. The disc jockeys also mentioned the need to further adjust the sound output in the mid-frequency range depending on how crowded the dance floor was. Controlling the effect of
reverberation, which generally reaches a maximum at 1000 Hz in large rooms (Hodgson, 1983), thus requires very significant adjustments in the response curves of the amplifiers. Due to a particular architectural design of discotheque D1, which further emphasized reverberation at 1000 Hz, the sound generation response curve adjustments did not fully compensate for such an effect. It should also be noted that the steep slope in the spectra below 63 Hz, observed in Figure 2, is the result of technological constraints with respect to sound power in the very low frequencies.

From a psychoacoustic standpoint, the three music spectrum design purposes reported above appear to converge in systematically compensating for the relative insensitivity of the human ear in the low frequencies. This is illustrated in Figure 3. The discotheque music spectrum from D2 (see Fig. 1) is compared with the mean free-field absolute hearing threshold curve (ISO R226, 1961) raised by 80 dB. The shape of the free-field hearing threshold curve can be considered as a valid descriptor of the combined external and middle-ear transfer function without the influence of the acoustic reflex (Dallos, 1973; Dancer, 1979). A similar curve is obtained when measuring the loudness level of short-duration high-level narrow-band impulse noises (Hétu et al., 1992). Exclusion of the contribution of the acoustic reflex is justified, considering that the latter shows a pronounced adaptation under uninterrupted sounds (Borg, 1976; Lalande, 1982). The similarity between the two curves reproduced in Figure 3 strongly suggests that sound technicians and disc jockeys intuitively shape the music spectrum so as to induce a sensation of loudness that is more or less equal at all frequencies between 63 and 6300 Hz. In the specific example of the spectrum from D2, it can be stated that, in terms of loudness level, the sound of the amplified music is slightly emphasized at 125, 500, 2500, and 3000 Hz, dropping noticeably above 6300 Hz. More generally speaking, it appears that the sound reproduction response curve is adjusted in a way that allows people to listen to musical sounds that induce a loudness sensation that is approximately constant at 80 dB above threshold across a wide range of frequencies.

It has been shown that exposure during 30 to 60 minutes at sound levels that are 80 dB above threshold induces temporary threshold shifts (TTS), which can amount to 15 to 17 dB on average (Botte et al., 1990). Thus, a 1-hour exposure to music in discotheque D2 would typically induce a significant amount of TTS across the entire frequency range between 63 and 6300 Hz. In the most sensitive individuals, it would amount to approximately 30 dB. In essence, a relatively short exposure period implies further music listening with fatigued ears. TTS is but one manifestation of auditory fatigue. It is associated with an altered perception of loudness, impaired pitch perception, reduced frequency selectivity, and temporal resolution, as well as reduced spatial resolution at high sound levels (Hétu, 1994a). In other words, attenders lose part of their auditory acuity while listening to their preferred music. This may appear as a paradox to a hearing specialist but probably not to an attendant, considering the actual experience of discotheque music listening, as discussed below.

PHENOMENOLOGY OF DISCOTHEQUE MUSIC LISTENING

Based on the above psychoacoustic description, and the accounts given by the sound technicians and disc jockeys interviewed, a preliminary phenomenology of discotheque music listening can be proposed. This phenomenology can be analyzed in terms of four basic dimensions of the dyadic experience (dancing with a partner), as well as the group experience of discotheque music listening. These are (a) confinement, (b) immersion, (c) passive hearing, and (d) excitement.

Confinement

The music sound power is such that practically no acoustic event that would remind people of the external world can penetrate the music environment. However, to achieve an effective acoustic shield, the music needs to be

![Figure 3](image-url)
uninterrupted. Thus, each new musical piece overlaps the preceding one.

**Immersion**

Because of the high sound power and the very limited dynamic range of the music, acoustic perspective disappears. Such restriction in the depth of the sound field is further enhanced by the absence of directionality of the sound sources and the salience of the low frequencies underlying the diffusive character of the music. The attenders feel immersed in a shared musical sound field.

In other words, discotheque music is not listened to; it “possesses” those who hear it (Schafer, 1985). People immerse themselves in a common acoustic space that is highly energizing. It can be considered as a particular type of “mechano-acoustic” arouser that is generally enjoyed by young people.

The above phenomenologic description is a starting point that needs to be completed by systematic analysis of the statements of discotheque attenders. An anthropologic approach is needed to understand the psychosocial function of loud music listening, especially as it may be associated with a risk of damage to hearing.

**Passive Hearing**

At high sound levels, frequency resolution is restricted (Zwicker and Fastl, 1990). The low-frequency content of the music tends to mask the higher frequency components so that the words of the songs are hardly intelligible and the sounds of the various musical instruments are more or less fused in a whole. The music itself is based on relatively simple and repetitive patterns. These various features of the music are designed to allow people to hear the music without having their attention solicited. It is thus a passive hearing experience as opposed to attentive listening.

**Excitement**

The salience of the rhythm, stressed by both the lower and higher frequency components, induces a strong auditory sensation of accelerated pulsation. The latter is perceived as auditory and proprioceptive sensations as well, because of the vibration induced in various parts of the body by the low-frequency rhythmic sounds. Feeling music through one's body parts is a type of sensation that was uncommon in western cultures before the introduction of rock concerts and discotheque music. Such proprioceptive sensations are now sought as an integral part of this “listening” experience. Furthermore, based on vestibular responses to acoustic stimulation observed both on an animal model (Cazals, 1983) and on humans (Colebatch et al., 1994), one could raise the possibility that the pulsating sounds are also exciting the vestibular system. As well, the pulsating lights, synchronized to the music beat, act on the balance system (Nashner, 1992) and further enhance the excitement that is expressed in the rhythmic dance movements.

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**LIMITING THE POTENTIAL RISK OF HEARING DAMAGE AMONG LISTENERS OF HIGHLY AMPLIFIED MUSIC**

Alarmist reports began to be issued as soon as rock concerts became popular (Lipscomb, 1969). Given that such reports correspond to the expectations of parents, as well as of hearing specialists, they received a wide but mostly uncritical audience. Expectations of this nature are still common. They are further reinforced by the perspective generally shared by scientists and professionals involved in hearing conservation in industry, that nonoccupational noise exposure is very often responsible for industrial workers’ hearing loss (Hétu, 1994b). It is revealing, in that respect, that the press coverage of a recent conference on noise and hearing loss sponsored by the National Institutes of Health (1990), concurred in emphasizing the risk of hearing damage from leisure activities such as loud music listening (Noble, 1991). This was based on possibilities rather than on actual firm evidence put forward by investigators.

Such evidence can be provided by means of two types of epidemiologic investigations: cross-sectional and longitudinal. Among the very few cross-sectional studies that were properly designed, any reliable effects of loud music listening that were observed were very slight or nonexistent (Fearn, 1976a, b, 1981; Axelsson and Lindgren, 1981; Carter et al., 1982, 1985). Furthermore, the controlled longitudinal studies published to date (Fearn, 1981; Carter et al., 1984) have drawn negative conclusions; no measurable effect of loud music exposure over 7 to 8 years among 141 teenagers was obtained (Carter et al., 1984).

At this time, there is no strong evidence demonstrating significant hearing damage from this new lifestyle habit of highly amplified music
listening. Risk estimates have been suggested based on generalized dose-response relationships, assuming continuous 8-hour daily exposure over different numbers of years in industry. There are, obviously, shortcomings associated with such a procedure. A representative sampling of loud music attendance patterns in the population is difficult to achieve and is currently lacking (Medical Research Council, 1986). Reliance on industry-based dose-response relationships implies a certain amount of extrapolation, and this is further compounded by the fact that the exposure pattern to music differs considerably from near-daily industrial exposure over decades.

Median discotheque attendance has been described as corresponding to an equivalent continuous A-weighted sound exposure for 4 hours ($L_{Aeq4h}$) at 97 dB with a corresponding weekly exposure ($L_{Aeq70h}$) of 87 dB (Bickerdike and Gregory, 1980). No study has yet been conducted to verify if a single weekly exposure for 4 hours at 97 dBA over 7 years (a duration that is typical of discotheque attendance) would induce the same effect as exposure at 87 dBA for 8 hours, 5 days a week, for the same number of years. Calculating the total sound energy may overestimate the risk of hearing loss because of the possibility for the ear to completely recover from auditory fatigue between two loud music attendances. Furthermore, the spectrum of amplified music, with its emphasis on the low frequencies, as shown in Figure 2, may not, at equal dBA levels, be strictly comparable in terms of noxiousness to the more flat spectra that are typical of industrial noise (Burns and Robinson, 1970).

It is worth mentioning that live music attendance has been shown to involve exposure levels that are generally more severe than discotheque attendance (Medical Research Council, 1986). However, the frequency of concert attendance is lower, and risk estimates based on total energy are, in such instances, even more uncertain.

Careful risk estimates, nevertheless, suggest that a small fraction of young people expose themselves for a sufficient number of hours weekly to sound levels high enough to sustain significant degrees of hearing loss (Medical Research Council, 1986). But any quantitative estimate is, as yet, highly uncertain and needs empirical validation. This conclusion does not imply that such a risk should be viewed as negligible. Of particular concern is the lack of data on tinnitus induced by loud music exposure. Severe handicaps can result from such a condition, which may result from a single instance of excessive exposure. Studies are badly needed in that area.

Listening to loud music is an evolving cultural practice subject to commercial solicitation. New trends are emerging that will take advantage of further developments in sound reproduction technology. Thus, it is reasonable to anticipate that the sound exposure levels to popular music will continue to escalate. In that respect, one of the most recent music styles, “rave,” seems to represent a concrete step in such a progression. Sound is produced with the addition of loudspeakers in the very low frequency range, tempos are faster than 120 beats per minute, and sound levels possibly higher than 100 dBA.

Another matter of concern is the use of portable cassette players. As with discotheques and rock concerts, alarmist statements have drawn the interest of hearing specialists to the potential risk associated with the use of portable cassette players. Maximum output levels from 110 dBA (Catalano and Levin, 1985) to 128 dBA (Katz et al, 1982) have been reported following measurements performed with artificial ears. However, such values cannot be compared with a generalized dose-response relationship such as the ISO 1999.2 standard (1989), whereby dose is assessed with measurements of sound level in diffuse sound fields. In order for earphone outputs to be compared with such levels, an acoustic mannequin such as the KEMAR must be used, and eardrum-to-diffuse-field transformation ratios must be introduced in the measurement. Using this procedure, reported A-weighted maximum output levels were as follows: 98 (Skrainar et al, 1987), 99 (Turunen-Rise et al, 1991), 102 (Bradley et al, 1987), and 107 dB (Rice et al, 1987a). When the highest of these values is combined with descriptors of listening habits based on a survey conducted in three European cities, the resulting $L_{Aeq70h}$ amounts to a maximum of 97 dB, with a median of 73 dB (Rice et al, 1987a). More data are needed on listening habits, as they are subject to several sociocultural influences, and their characterization by means of self-reports can be underestimated. The above exposure levels nevertheless provide an indication that the risk of hearing damage is relatively low and most likely restricted to a very small segment of the population. Those at risk are listening to the more powerful cassette players set at almost maximum sound level for extensive periods of time weekly.
CONCLUDING REMARKS

In view of the potential risk of hearing damage due to amplified music, hearing specialists have been inclined to adopt a prescriptive and somewhat reproachful attitude toward those who are regularly exposed to highly amplified music. This attitude probably reflects an element of culture shock tied to a health concern. Health education as a discipline has clearly demonstrated that reproaches have very little effect on unhealthy practices (Rogers, 1983). In fact, a majority of teenagers appear to be informed of the fact that listening to music at very high sound levels may damage their hearing (Rice et al, 1987b; Lewis, 1989). However, being informed of a risk does not, in itself, change behavior. In fact, the need to preserve one’s hearing is not felt to be as important by youth because the consequences of hearing loss are simply unknown or not perceived to be serious, as is also the case among industrial workers (Hétu et al, 1994). Accordingly, effective descriptions of the effects of hearing loss in terms of everyday limitations and long-term psychosocial disadvantages, such as reduced social participation, should be provided rather than anatomical or audiometric correlates of hearing loss.

Furthermore, the need for prevention, if felt even slightly, is competing with other much more powerful needs, such as sharing a sound space with one’s peers, feeling the excitement induced by loud music attendance, and the ensuing escape from boredom or problems. With portable cassette players, music can also serve to cut oneself off from one’s surroundings while traveling or performing other daily activities (Hellbrück and Schick, 1990). From this perspective, effective prevention of hearing damage from listening to loud music presupposes a proper understanding of the needs met by this type of practice. Once such needs are known, it should be possible to propose listening conditions that offer the expected benefits without creating a significant risk to hearing. Specifically, it should be possible to create impressions such as confinement, immersion, and excitement without inducing significant amounts of TTS and, accordingly, without any risk of permanent damage. This would first require a well-grounded understanding of what is actually being sought while listening to loud music in specific social contexts. Experimentation with the spectral shape and the level of the music in those contexts might lead to the attainment of satisfactory listening conditions. In other words, psychoacoustics may play a role in facilitating the experiences sought when listening to amplified music, by careful manipulation of the acoustic features of that music in relation to the specific desired sensations. Performed within the boundaries of the ear’s physiologic tolerance to high sound energy, such experiments could serve as reference for both sound technicians and manufacturers of audio equipment, in their effort to engineer access to safe as well as satisfactory music listening.

Listening to highly amplified music is now a common habit that sustains a very active industry. Its casualties in terms of hearing damage are most likely those whose occupation requires exposure to amplified music (Fortin and Hétu, 1994). Such people make up a broad area of intervention that has been somewhat neglected by audiologists to date, as well as by occupational health inspectors.

Among those professionals who can exert some form of control over their exposure levels, various technical devices and procedures might be tested in order to achieve a safe exposure level without interfering with task performance (Fortin and Hétu, 1994). For those who cannot exert such a control, sound level reduction is needed, especially as these professionals generally need to communicate verbally. This approach, at first sight, contradicts the interests of those who operate premises involving amplified music listening, as the latter are primarily trying to satisfy their customers. Accordingly, reducing the music levels presupposes some form of effective sensitization of the customers to the risks and consequences of hearing damage. As discussed above, such sensitization, in turn, requires a proper understanding of the effects that are sought in listening to amplified music and the design of music features that would allow young people to meet their needs without incurring hearing damage. Such understanding can eventually be achieved as a result of a careful analysis of the actual experience of listening to loud music in specific social contexts. It calls for multi-disciplinary investigations involving not only hearing specialists but also psychologists, musicologists, and anthropologists. Although complex and resource consuming, such investigations are probably the only avenue toward a healthy social integration of the recently adopted practice of listening to highly amplified music.
REFERENCES


