LOUD MUSIC INDUCED THRESHOLDShifts AND DAMAGE RISK PREDICTION

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Temporary thresholds shifts in musicians using high power electronic equipment were measured immediately after performance. The danger of permanent hearing loss is predicted on the ground of Damage Risk Criteria.

1. Introduction

The danger of hearing loss in musicians exposed to high sound pressure levels produced by electronic equipment, has been discussed over the past three decades, not only in scientific papers [2, 3, 6, 7, 9, 11, 16, 17, 20, 21, 26, 27, 28, 31, 32, 33, 34, 37, 38, 39, 40, 48] but also in popular literature [19] and in news articles [1, 15]. However, the results of acoustical measurements, and the conclusions of various investigations are not in agreement with respect to the distribution of sound pressure levels with frequency and to the degree to which such exposures are dangerous.

RINTELMANN and BORUS [33] determined the octave band distributions of sound pressure levels in 44 musical selections performed by 6 American rock-and-roll groups. The overall sound pressure level amounted to 105 dB with the range from about 91 to 111 dB. The sound pressure levels in the octave bands between 63 Hz and 2.0 kHz were practically constant at 95–100 dB, and decreased to about 75 dB at 31 Hz and 8.0 kHz, respectively. According to the so-called Damage Risk Criteria (DRC) [4, 6, 7, 22] prolonged exposures to noise at approximately these sound pressure levels are recognized as leading to permanent hearing loss. However, audiometric tests in the experimental group of 42 musicians did not display significant differences in hearing level with respect to the control group. The experimental group had but relatively short professional careers of 2.9 years duration on the average. KRYTER's [22] and KRYTER's et al. [23] data suggest that permanent hearing loss from exposure to noise at levels comparable to those reported by RINTELMANN and BORUS [33], is usually observed only after 10 years of service if the exposure is repeated 5 times a week.

It should be also observed that audiometric test data given in the mentioned report refer to permanent hearing loss, because the measurements were taken at least 48 hours
after the performance. In another report, Rintelmann et al. [34] had 20 subjects listen for an hour to rock-and-roll music and investigated temporary threshold shifts after 2, 30, 60 and 90 min. from the termination of the exposure. From hearing recovery patterns, it was concluded that daily exposures over an extended period would be hazardous to hearing.

Flugrath [15] measured the distribution of sound pressure levels in four octave bands for 10 music groups. In all groups investigated, the highest sound pressure levels of about 100 dB were observed only within the octave bands centered at 1 and 2 kHz and decreased to about 90 dB in the 0.5 kHz and 4 kHz octave bands. Flugrath formulated his conclusions using the data by Kryter [22] and Kryter et al. [23] based substantially on investigations by Ward et al. [41, 42, 44, 45], Carter and Kryter [8] and Kryter's et al. [23] and by Botsford [4]. With reference to these data, Flugrath stated that at a sound pressure level of 102 dB in the 2 kHz octave band, the permissible daily exposure should not exceed 12 minutes. It is quite obvious that in normal practice the daily exposure is significantly larger and should be regarded as potentially dangerous.

J Berger and J Berger [20] reported observations of the temporary thresholds shift in musicians from two music groups. They were exposed to sounds at sound pressure levels of 110 to 120 dB within the 600–1200 Hz octave band over a period of 4 hours. In one of the groups investigated, 30 to 50 dB temporary threshold shifts were observed 1 hour after the exposure. In the second group (comparatively younger), all musicians had TTS's ranging from 15 to 30 dB in at least one ear. Referring to Kryter's [22, 23] data, the authors estimated the permissible daily exposures in similar situations at only 9 to 22 min. for the 300 to 600 Hz band and from 5 to 11 min. for the 600 to 1200 Hz band. It should be emphasized, that in one of the groups permanent hearing losses of 30–70 dB in at least one ear were found in three musicians. Berger and Berger measured TTS only 1 hour after the performance. The TTS immediately after exposure may have been as much as 30 dB higher (Kryter [22, 23]).

It is very important to note that both Kryter's [22, 23] and Botsford's [4] data on permissible exposures are based on the measurements of the impairment of speech recognition by 10%. This criterion was determined for industry employers. With regard to musicians, however, its direct application may not be quite proper.

The purpose of this study was to determine the distribution of sound pressure levels in octave bands in a typical rock music performance in Poland, to measure temporary thresholds shifts in the performing musicians immediately after the exposure, and to evaluate the danger of hearing loss. Control audiometric measurements of hearing loss one year after the first measurements were made to find out if the impairment of hearing can be detected, inasmuch as it can be predicted from the results published by Robinson [35] and Ward [47].

2. Subjects

The group of musicians tested were four members of one of the recognized music groups, aged 22 to 29, all graduates of music schools. Two of them played two instruments, i.e. saxophone and flute, saxophone and piano, two others—percussion and bass guitar. The experience in musical performance with high power electronic equipment differed
among individuals from 2 to 8 years and averaged 3.5 years. Usually the group gave three performances a week, lasting about 4 hours each, including 10 min. break after each three music pieces. The total playing time of the group including public performance and rehearsal amounted to 20 hours weekly.

3. Sound pressure level measurements

The measurements of sound pressure levels were made at the students’ club dance hall. Direct sound pressure level indications oscillated between 90 and 120 dB. A routine musical performance was recorded on magnetic tape. The microphone was placed 2 m above the floor at a distance 1.5 m from the orchestra on the geometrical axis of the hall. With this arrangement a reference signal (horn sound) was recorded at the beginning of each tape reel. The sound pressure level of this reference signal, measured directly at the microphone location was 120 dB SPL. Twelve musical selections representative of the performance of the group were recorded. The material obtained was analyzed for the distributions of sound pressure levels in the successive octave bands.

4. The analysis of sound pressure distribution

The LTAS (Long Term Average Spectra) analysis revealed that the sound pressure levels over the separate musical selections were substantially constant except for the beginning fractions lasting about 5 to 15 sec. each. Therefore, only short samples from each of the records were selected for the analysis. The first 15 seconds from each record were discarded and the subsequent 50 seconds were used for LTAS analysis.

Sound pressure levels in the successive octave bands centered at 0.5, 1.0, 2.0 and 4.0 Hz, overall linear $L$, overall $A$ and $C$ weighted (Brul and Kjaer) were computed. Median values for the sound pressure levels $L$, $A$, $C$ and the maximum deviations of these values are presented in Fig. 1A.

Median values of the sound pressure levels referring to the maximum and to the mean sound pressure levels in separate octave bands and maximum deviations of these values are presented in Fig. 1B. Median values and maximum deviations of the mean sound pressure levels computed for 10 American musical groups after Flugrath [16] as well as data published by Rintelmann and Borus [33] and Fearn [13] are presented in the same figure for comparison.

It can easily be seen that sound levels produced by the music group used in the present investigation are within the limits determined by Flugrath except for the 0.5 kHz octave band. Even in this case, however, the difference is not substantial. In general, the group used in present investigations produced slightly higher- over-all sound pressure levels than those studied by Flugrath, but not so much different from the data of Bohne et al. [3], Fearn [11, 12, 13] and Lebo and Olifant [26].

In all cases, sound pressure levels measured in this study for the rock music performances are higher than those permissible in industrial plants. According to Botsford [4], the permissible daily exposure under the conditions presented in this analysis should not exceed 15 min. Thus, the daily dose of 4 hours exposure is 16 times larger than permissible.
5. Hearing thresholds measurements

Threshold measurements in performers of rock music were made using a clinical audiometer at 10 frequencies within the range from 125 Hz to 100 kHz. The audiometer was calibrated to audiometric zero level for the 18 to 25 years of age category.

The measurements were made 48 hours after the exposure (resting hearing level) and almost immediately after the exposure. Temporary thresholds shifts for the four musicians were determined as differences between resting hearing levels and hearing levels after 5, 9, 11 and 14 min. after termination of the exposure respectively. The determined values of TTS₁ (TTS₅, TTS₉, TTS₁₁, and TTS₁₄) were next used to find TTS₂ values (TTS that would be 2 min after the termination of the exposure). This procedure, introduced by KRYTER [22] and KRYTER et al. [23], is based on the time dependence of the magnitude of TTS which was investigated thoroughly by NIXON and GLORIG [29], KRYTER [22], BOTSFORD [4] and others.

The graphs in Figs. 2 to 5 present resting hearing levels measured and hearing levels two minutes after the exposure estimated. The difference of these two levels corresponds to the amount of TTS₂ i.e. temporary threshold shift 2 min after termination of the exposure.

Intersubjects median values of the temporary and permanent hearing losses and the maximum deviations of these values are presented in Figs. 6 and 7 for the right and left ears of all subjects. Median temporary thresholds shifts in Figs. 6 and 7 reach 30 dB at 1 kHz and slightly over 40 dB at 4 and 6 kHz for both ears. However, individual TTS₂
Fig. 2. Hearing level. Subj. A., resting and 2 min after exposure. Sax and flute, two years of performance with electronic equipment.

Fig. 3. Hearing level. Subj. B., resting and 2 min after exposure. Sax and piano, two years of performance with electronic equipment.
Fig. 4. Hearing level. Subj. C., resting and 2 min after exposure. Percussion, eight years of performance with electronic equipment.

Fig. 5. Hearing level. Subj. D., resting and 2 min after exposure. Bass guitar, two years of performance with electronic equipment.
Fig. 6. Intersubject medians and maximum deviations of threshold values, 2 min and 48 hrs after exposure. Right ears of all subjects.

Fig. 7. Intersubject medians and maximum deviations of threshold values, 2 min and 48 hrs after exposure. Left ears of all subjects.
which may be found in Fig. 2 through 5 reach much higher values (e.g. subject A right ear, 6 kHz: TTS equal 70 dB).

The median values of resting hearing levels (threshold 48 hours after the exposures) reach 20 dB reaudiometric zero level for both ears and reveal moderate permanent hearing loss in all musicians. The inspection of individual resting hearing levels in Fig. 2 through 5 shows marked individual differences. In musician C (Fig. 4) a permanent hearing loss of about 50 dB (in between 4 and 6 kHz) in both ears is observed. Since this musician had no record of any other injury-producing exposure, the observed bilateral hearing loss have most probably resulted from his exposure to music.

This supposition was, in a measure, confirmed by measurements of hearing threshold in all musicians, which were performed 12 months after the first measurements. Further impairment of hearing in musician C, an additional hearing loss of 15 dB at 2 kHz was found. In other musicians, no significant changes were observed, new data being in agreement with the previous ones within 6 dB, which could be assigned to natural resting hearing level fluctuations. It may be argued that musician C was particularly susceptible to high sound pressure level exposures.

6. Threshold recovery

The examination of threshold recovery (Fig. 8) shows that most of the recovery process takes place within about 30 min of the end of exposure. Two types of recovery curves can

![Threshold recovery graph](image-url)

**Fig. 8.** Threshold recovery for subjects A, B, C and D at the frequencies where maximum TTS was observed. A — left ear 6 kHz — closed triangles pointed up, A — right ear 6 kHz — closed circles; B — left ear 8 kHz — closed triangles pointed down, B — right ear 8 kHz — open circles; C — left ear 2 kHz — open squares; D — left ear 6 kHz — open triangles pointed up, D — right ear 6 kHz — closed squares.
be distinguished, i.e. corresponding to the approximately linear recovery in logarithmic time coordinates (subject A, left ear), and these with a more or less distinct change of the slope at 20 to 30 min.

7. Discussion

It is known from the literature [4, 22, 29] that if an exposure leading to a given threshold shift TTS$_2$ is repeated 5 times a week for about 10 years, it results in a permanent hearing loss equal to the observed TTS$_2$. It should be apparent from this reasoning that, in the musicians in this investigation, severe permanent hearing losses can be predicted.

It may be interesting to compare the predicted hearing losses with damage risk criteria for industrial workers. The Damage Risk Criteria (or DRC) defined by KRYTER [22] and BOTSFORD [4] are based on the results of investigation of speech intelligibility impairment by 10%. Permissible hearing loss according to these criteria amounts to 10 dB at 1 kHz, 15 dB at 2 kHz, and 20 dB at 3 kHz [22], or 30 dB at 1 kHz, 45 dB at 2 kHz and 60 dB at 3 kHz. Compared with these two sets of values, the permanent hearing losses that can be predicted from the TTS$_2$ values observed in the musicians tested are larger than permissible.

The notion of permissible hearing losses requires some additional consideration. It should be noted that no general agreement has been achieved concerning the sound pressure level at which a speech intelligibility test for establishing the DRC should be performed. Also, the speech intelligibility tests are often run without masking of any kind, and, therefore, the results obtained do not reveal the actual impairment of hearing, which in practice is more severe. Therefore, it cannot be assured that the above specified permissible hearing losses under actual environmental conditions and, particularly, in the presence of masking do not result in an "operational impairment" of hearing ability higher than the assumed 10%. In the case of musicians, hearing losses which lead only to the impairment of speech intelligibility but also to some deterioration of professional ability to discriminate timbre of musical sounds, are of particular importance.

Therefore, the above discussed "permissible" hearing losses should be regarded as not permissible. Such losses may result in a considerable decrease of professional efficiency in musicians after only 10 years of activity. However, people differ in their susceptibility to noise (LARSON [25], WARD [46], HARRIS [18], CHUNG et al. [19]). The same is most probably also true for exposures to high-level music. Hazards of listening to music through high-power electronic equipment may be substantially larger to some musicians e.g. one subject C than to others. The result of the present study suggest that in any case these hazards are substantial.

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