ARCHIVES OF ACOUSTICS
19, 3, 311–321 (1994)

LOUD MUSIC INDUCED THRESHOLDS SHIFTS AND DAMAGE RISK PREDICTION

A. JAROSZEWSKI and A. RAKOWSKI

Frederic Chopin Academy of Music
(00-368 Warszawa ul. Okólnik 2)

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.

JERGER and JERGER [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. Jerger and Jerger 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 (Bruel 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.

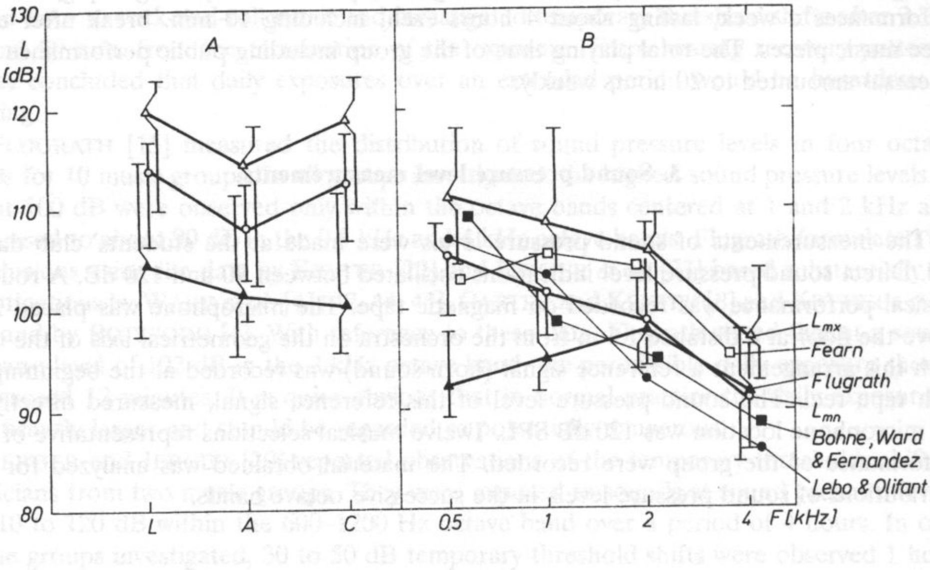

FIG. 1. A):. Median values and interquartiles of maximum (open triangles) and mean (open circles) sound pressure levels. Closed triangles — data from FLUGRATH. L-linear, A — A weighted, C — C weighted; B): Median values and interquartiles of maximum (L_{mx} — open triangles) and mean (L_{mn} — open circles) sound pressure levels in successive octave bands. Data from other authors indicated.

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 TTS_t (TTS_5, TTS_9, TTS_{11} and TTS_{14}) were next used to find TTS_2 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 TTS_2 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 TTS_2

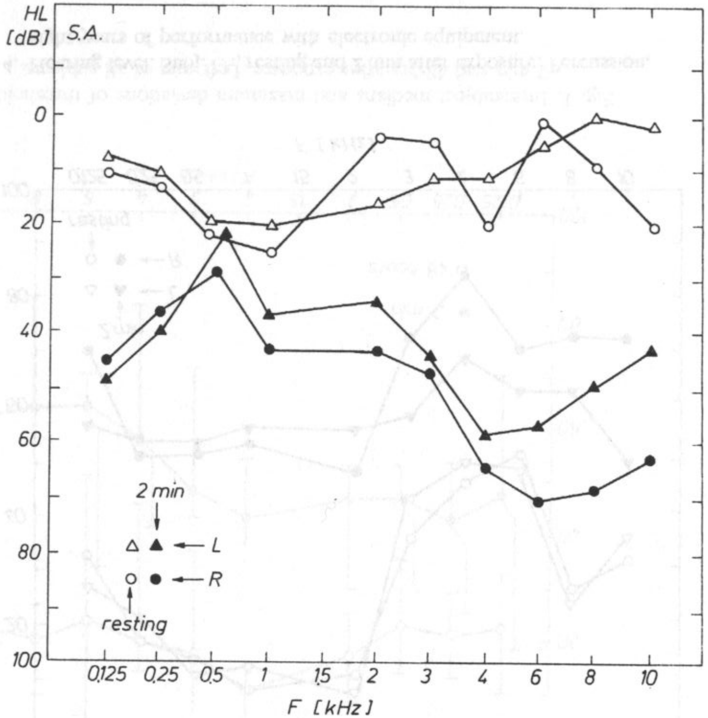

Fig. 2. Hearing level. Subj. *A.*, resting and 2 min after exposure. Sax and flute, two years of performance with electronic equipment.

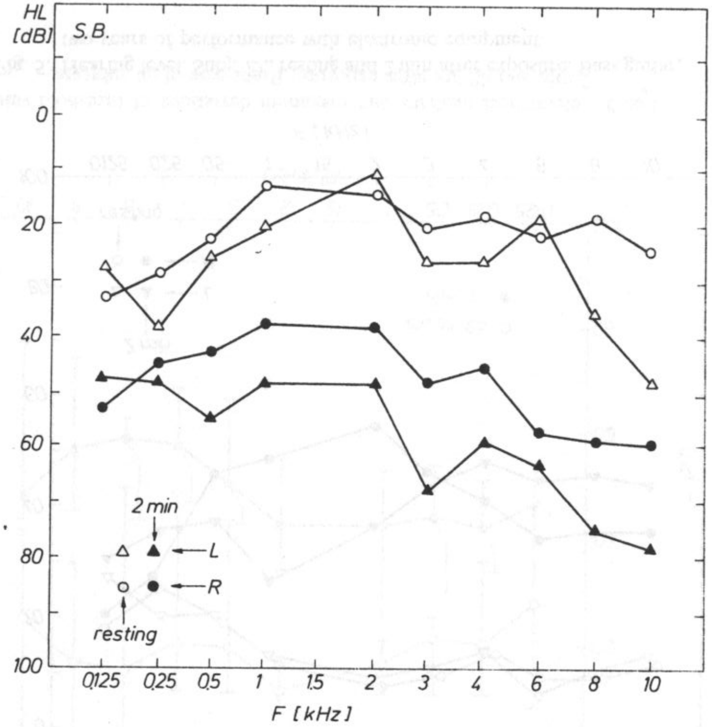

Fig. 3. Hearing level. Subj. *B.*, resting and 2 min after exposure. Sax and piano, two years of performance with electronic equipment.

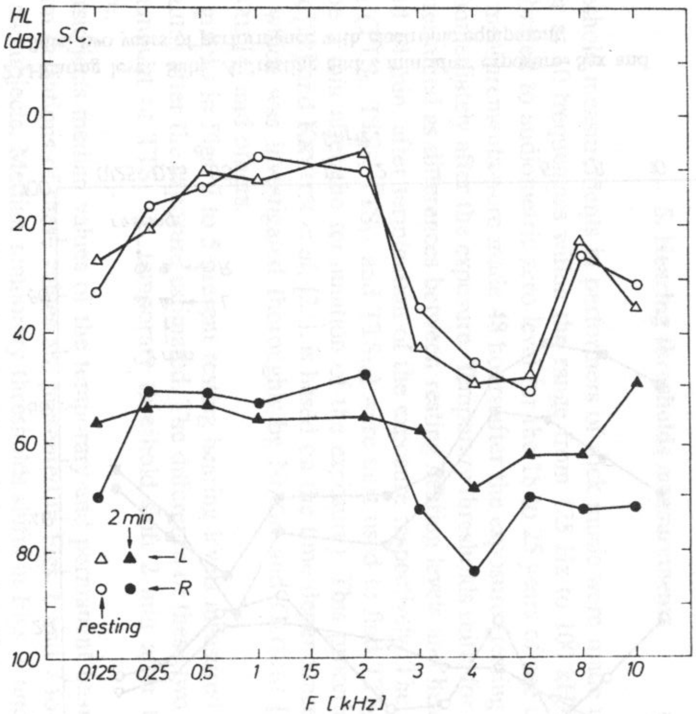

Fig. 4. Hearing level. Subj. *C*., resting and 2 min after exposure. Percussion, eight years of performance with electronic equipment.

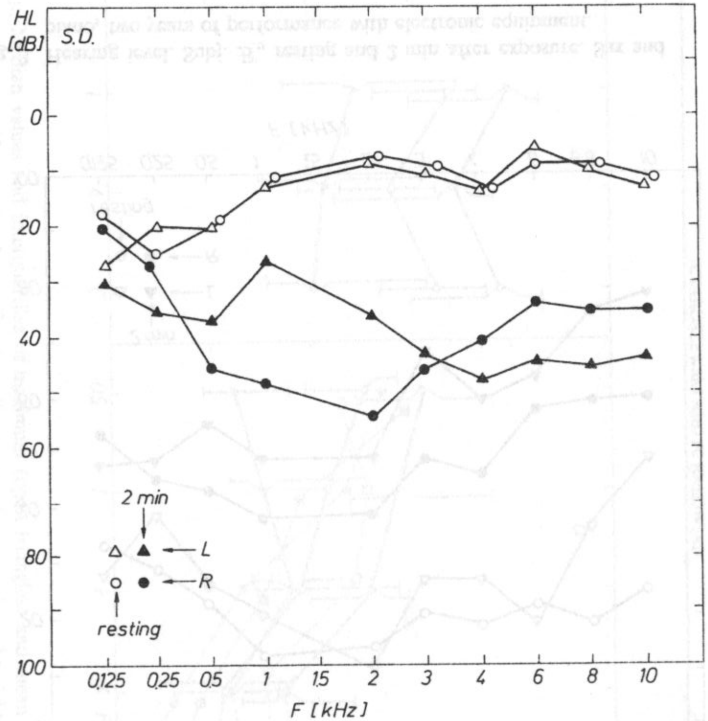

Fig. 5. Hearing level. Subj. *D*., resting and 2 min after exposure. Bass guitar, two years of performance with electronic equipment.

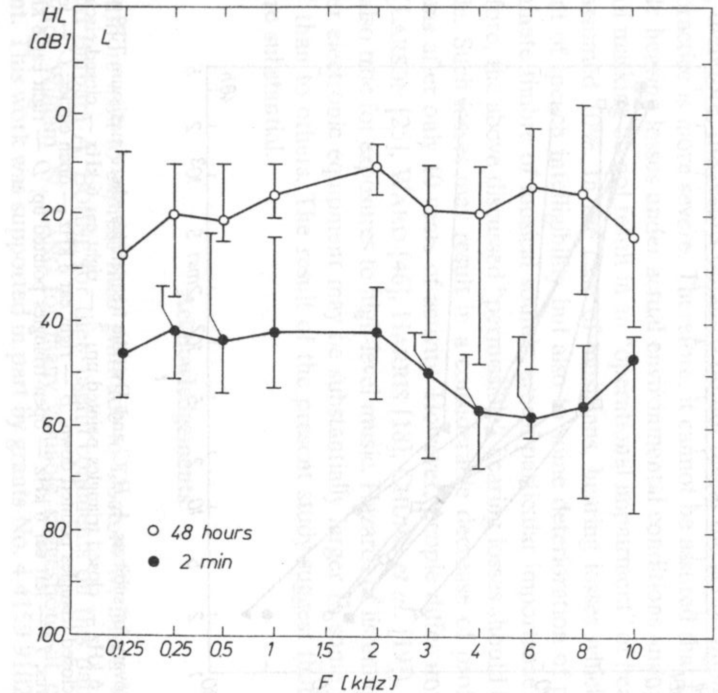

Fig. 6. Intersubject medians and maximum deviations of threshold values, 2 min and 48 hrs after exposure. Right ears of all subjects.

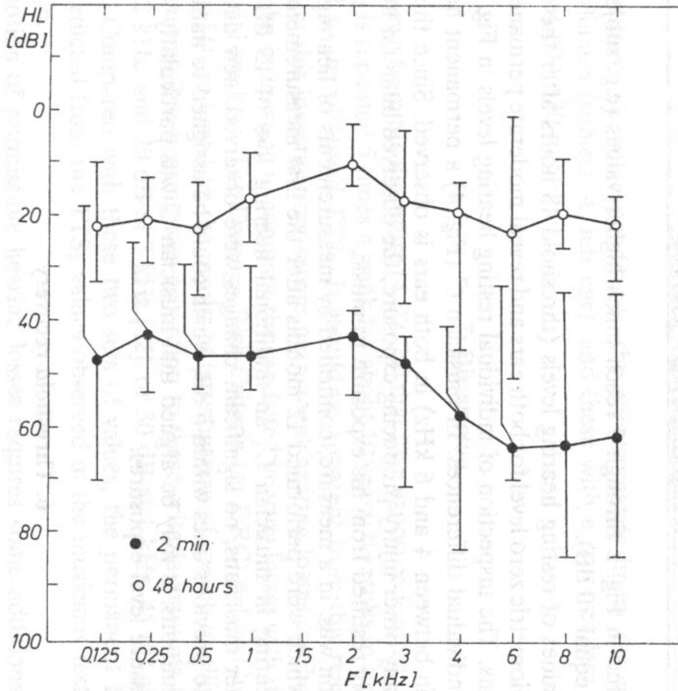

Fig. 7. Intersubject medians and maximum deviations of threshold values, 2 min and 48 hrs after exposure. Left ears of all subjects.

which may be found in Fig. 2 through 5 reach much higher values (e.g. subject A right ear, 6 kHz: TTS_2 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

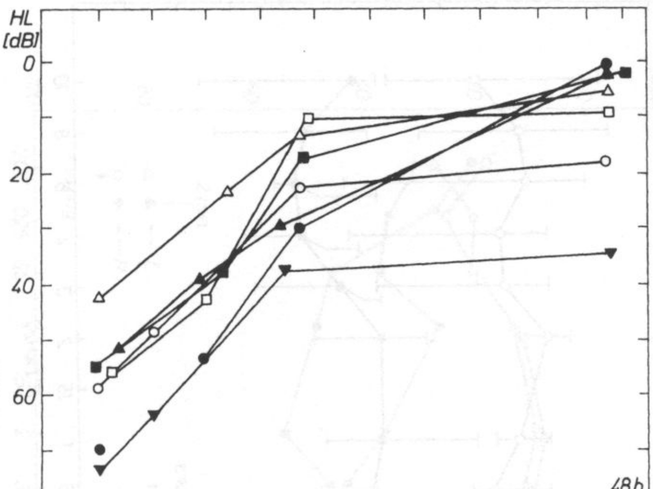

FIG. 8. Threshold recovery for subjects A, B, C and D at the frequencies where maximum TTS was observed. A — left ear 6 kHz — closed triangles pointed up, A — right ear 6 kHz — closed circles; B — left ear 8 kHz — closed triangles pointed down, B — right ear 8 kHz — open circles; C — left ear 2 kHz — 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 weak 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 that 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.

Acknowledgements

The authors wish to express their gratitude to Doctors W. Dixon WARD, William W. CLARC and Barbara A. BOHNE for their useful comments on this paper. Special thanks go to Doctor William W. LANG for many valuable suggestions at early stages of the experiment. This work was supported in part by grants No. 4 4159 9102 and 4 4075 92 03.

References

[1] Annon. Going deaf from rock'n'roll. Time 47, Aug. 9 (1968).

[2] A. AXELSSON and F. LINDGREN, *Hearing in classical musician*, Acta Oto-laryngological, Supplement 337 1981.

[3] B.A. BOHNE, P.H. WARD and C. FERNANDEZ, *Irreversible inner ear damage from rock music*, Trans. Amer. Acad. Phtalm. Otolaryng., 50–59 (1976).

[4] J.H. BOTSFORD, *Simple method for identifying acceptable noise exposure*, J. Acoust. Soc. Amer., **42**, 810–819 (1967).

[5] J.H. BOTSFORD, *Theory of temporary threshold shift*, J. Acoust. Soc. Amer., **49**, 440–446 (1971).

[6] A. BURD, *Hearing damage from music -UK experience*, J. Audio Eng. Soc., Sept. 1974.

[7] W. BURNS and D.D. ROBINSON, *Hearing and noise in industry*, HMSO 1970.

[8] R. CARTER and K.D. KRYTER, *Equinoxius contours for pure tones and some data on the critical band for TTS*, Bolt Beranek and Newman Inc., Rept. No 948 (1960).

[9] D.Y. CHUNG, G.N. WILLSON, R.P. GANNON and K. MASON, *Individual susceptibility to noise*, in: R.P. Hamernick, D. Henderson and R. Salvi Eds, New perspectives on noise-induced hearing loss, Raven Press, New York 1982.

[10] H. DAVIS, G.T. MORGAN, J.E. HAWKINS, R. GALAMBOS and F.W. SMITH, *Temporary deafness following exposure to loud tones and noise*, Acta Oto-Laryngol., Suppl. 88 (1950).

[11] R.W. FEARN, *Noise level in youths clubs*, J. Sound Vib., **22**, 126–128 (1972).

[12] R.W. FEARN, *Pop music and hearing damage*, J. Sound Vib., **29**, 396–397 (1973).

[13] R.W. FEARN, *Level limits on pop music*, J. Sound Vib., **38**, 501–502 (1975).

[14] R.W. FEARN, *Level measurements of music*, J. Sound Vib., **43**, 588–591 (1975).

[15] J.M. FLUGRATH, *Modern-day rock-and-roll music and damage risk criteria*, J. Accoust. Soc. Amer., **45**, 704–711 (1969).

[16] J.M. FLUGRATH, *Temporary threshold shift and permanent threshold shift due to rock-and-roll music*, J. Acoust. Soc. Amer., **51**, 151A (1972).

[17] H.J.H. FRY, *Overuse syndrome in musicians — 100 years ago: an historical review*, The Medical Journal of Australia, **145**, 620–625 (1986).

[18] J.D. HARRIS, *Hearing loss trend curves and the damage-risk criterion in Diesel-engineering personnel*, J. Acoust. Soc. Amer., **37**, 444–452 (1965).

[19] A. HOPE, *Hearing damage*, Studio Sound, Aug. **48** (1975).

[20] S. JERGER and J. JERGER, *Temporary threshold shift in rock-and-roll musicians*, J. Speech Hear. Res., **13**, 221–224 (1970).

[21] D.W. JOHANSON, R.E. SHERMAN, J. ALDRIGE and A. LORAINE, *Effects of instrument type and orchestral position on hearing sensitivity for* 0.25 *to* 20 kHz *in the orchestral musician*, Scandinavian Audiology, **14**, 215–221 (1985).

[22] K.D. KRYTER, *Exposure to steady-state noise and impairment of hearing*, J. Acoust. Soc. Amer., **35**, 1515–1525 (1963).

[23] K.D. KRYTER, W.D. WARD, J.D. MILLER and D.H. ELDREDGE, *Hazardous exposure to intermittent and steady-state noise*, J. Acoust. Soc. Amer., **39**, 451–464 (1966).

[24] K.D. KRYTER, *The effect of noise on man*, Academic Press, New York, London 1970.

[25] B. LARSEN, *Occupational deafness*, Acta Ot-Laryngol., **41**, 139–157 (1952).

[26] C.P. LEBO, K.S. OLIPHANT and J. GARRET, *Acoustic trauma from rock-and-roll music*, Calif. Med., **107**, 378–380 (1967).

[27] C.P. LEBO and K.S. OLIPHANT, *Music as a source of acoustic trauma*, Laryngoscope, **78**, 1211–1218 (1968).

[28] D.M. LIPSCOMB, *Ear damage from exposure to rock-and-roll music*, Arch. Otolaryng., **90**, 545–555 (1969).

[29] J.C. NIXON and A. GLORIG, *Noise-induced permanent threshold shift at* 2000 *cps and* 4000 *cps*, J. Acoust. Soc. Amer., **33**, 904–908 (1961).

[30] J.C. NIXON and A. GLORIG, *Noise-induced permanent threshold shift vs. hearing level in four industrial samples*, J. Audit. Res., **2**, 125–138 (1962).

[31] J. RABINOWITZ, R. HANSLER, G. BRISTOWN and P. RAY, *Study of the effects of loud music on musicians of the Suisse Romande Orchestra*, Journal de Medicine et Hygiene, **19**, 1909–1921 (1982).

[32] C.G. Rice, J.B. Ayley, R. Bartlett, W. Bedford, W. Gregory and G. Hallam, *A pilot study on the effects of pop group music on hearing*, J.S.U.R. Memo 266, Southampton: Univ. of Southampton Press (1968).

[33] W.F. Rintelmann and J.F. Borus, *Noise-induced hearing loss and rock-and-roll music*, Arch. Otolaryngol., **88**, 377–385 (1968).

[34] W.F. Rintelmann, R.F. Lindberg and E.K. Smittey, *Temporary threshold shift and recovery patterns from two types of rock-and-roll music presentation*, J. Acoust. Soc. Amer., **51**, 1249–1255 (1972).

[35] D.W. Robinson, *The relationship between hearing loss and noise exposure*, National Physical Lab. Report AC 32, Teddington, England (1968).

[36] G.T. Singleton, *Jet noise peak challneged by rock-and-roll*, Chicago Daily News, 22, March 12 (1968).

[37] E. Smitley and W.F. Rintelmann, *Effect at continuous versus intemittent exposure to rock-and-roll music upon temporary threshold shift*, Arch. Envir. Health, **22**, 413–420 (1971).

[38] C. Speaks and D.A. Nelson, *TTS following exposure to rock-and-roll music*, J. Acoust. Soc. Amer., **45**, 342A (1969).

[39] C. Speaks, D.A. Nelson and W.D. Ward, *Hearing loss in rock-and-roll musicians*, J. Occup. Med., **12**, 216–219 (1970).

[40] R.F. Ulrich and M.L. Pinheiro, *Temporary hearing loss in teen-agers attending repeated rock-and-roll sessions*, Acta Otolaryng., **77**, 51–55 (1974).

[41] W.D. Ward, A, Glorig and D.L. Sklar, *Dependence of temporary threshold shift at 4 kc on intensity and time*, J. Acoust. Soc. Amer., **30**, 944–954 (1958).

[42] W.D. Ward, A, Glorig and D.L. Sklar, *Temporary threshold shift from octave-band noise: applications to Damage Risk Criteria*, J. Acoust. Soc. Amer., **31**, 522–528 (1959).

[43] W.D. Ward, A, Glorig and D.L. Sklar, *Relation between recovery from temporary threshold shift and duration of exposure*, J. Acoust. Soc. Amer., **31**, 600–602 (1959).

[44] W.D. Ward, *Studies in the aural reflex. II. Reduction of temporary threshold shift from intermittent noise by reflex activity: implications for damage risk criteria*, J. Acoust. Soc. Amer., **34**, 234–241 (1962).

[45] W.D. Ward, *The use of TTS in the derivation of Damage Risk Criteria for noise exposure*, Int. Audiol., **5**, 309–313 (1966).

[46] W.D. Ward, *Susceptibility to TTS and PTS*, Proceedings of the International Congress on Noise as Public Health Problem, Dubrownik, Yugoslavia 1973.

[47] W.D. Ward, *The "safe" workday noise dose*, Noise, Shock and Vibration Conference 1974, Monash University, Melbourne, Australia 1974.

[48] D.H. Woolford, *Hearing impairment among Orchestral Musicians*, Music Perception **5**, 261–284 (1988).