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Effects of Exercise and Noise on Auditory Thresholds and Distortion-Product Otoacoustic Emissions

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Abstract

Differences in auditory thresholds and distortion-product otoacoustic emission (DPOAE) levels were investigated as a function of gender, ear, frequency, and experimental condition: quiet sedentary activity, exercise, noise, and exercise and noise combined. In general, participants displayed significant elevations in auditory thresholds of approximately 6 to 13 dB following the two conditions employing noise exposure. There were no significant differences in either auditory threshold differences before and following the quiet and exercise conditions or between the noise-alone and combined exercise and noise conditions. Participants also displayed significant reductions in DPOAE levels of approximately 6 to 7 dB following the two conditions employing noise exposure. The findings also showed no gender or ear effects on auditory threshold or DPOAE level differences. Further, there was no evidence of a synergistic combination of exercise and noise on auditory function as revealed by changes in hearing threshold or DPOAE levels.

Key Words: Auditory threshold, distortion-product otoacoustic emissions, exercise, noise

Abbreviations: DPOAE = distortion-product otoacoustic emissions, TTS = temporary threshold shift

Occupational and recreational noise-induced hearing loss continues to be a significant health concern. It is well understood that frequency, intensity, and duration influence the amount of temporary threshold shift (TTS) that progressively leads to permanent hearing loss. In addition, ancillary endogenous factors independent of the physical attributes of noise have been identified to influence an individual's susceptibility to TTS. Such factors include age (Humes, 1984), individual anatomic variations in the auditory periphery (Borg, 1968; Gerhardt et al, 1987), eye color (Hood et al, 1976; Cunningham and Norris, 1982; Barrenas and Lindgren, 1991), gender (Ward, 1966, 1973), psychological stress (Sandén and Axelsson, 1981; Lindgren and Axelsson, 1983; Bartsch et al, 1986; Swanson et al, 1987), and tobacco use (Zelman, 1973; Drettner et al, 1975; Dengerink et al, 1984).

Another concern for hearing conservationists is the role of physical exercise on the susceptibility of individuals to TTS. Several studies have found exercise and noise to be synergistic, leading to an increase in TTS relative to noise exposure alone (Lindgren and Axelsson, 1988; Colletti et al, 1991; Vittitow et al, 1994; Engdahl, 1996). It has been suggested that changes in metabolic activity (i.e., increases in core body temperature and release of catecholamines) and/or depression of the stapedius reflex during exercise are possible explanations for the synergistic increase in TTS. These findings, however, have been challenged by others who have reported that TTS is driven by noise exposure alone and not a combination of noise and exercise (Dengerink et al, 1987; Hutchinson et al, 1991; Alessio and Hutchinson, 1992; Manson et

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al, 1994; Mirbod et al, 1994). Admittedly, some differences in methodology (e.g., levels and durations of noise exposure and levels of physical exercise) may be attributed to the equivocal findings. Further, it has been demonstrated that an individual's level of physical fitness influences susceptibility to TTS (Manson et al, 1994; Kolkhorst et al, 1998).

A growing body of evidence demonstrating the greater sensitivity of distortion-product otoacoustic emissions (DPOAEs) over psychoacoustic and/or standard behavioral hearing in revealing the acute effects of noise (e.g., Attias and Bresloff, 1996; Engdahl and Kemp, 1996; Attias et al, 1998; Delb et al, 1999) would suggest that an investigation exploring the role of physical exercise on the susceptibility of individuals to TTS with DPOAEs would be profitable. To date, however, only one study has explored this. Engdahl (1996) examined changes in DPOAE levels and behavioral thresholds in eight participants prior to and following three experimental conditions (i.e., noise alone, exercise alone, and exercise and noise combined). Participants were exposed to 10 minutes of ⅓-octave noise of 102 dB SPL centered at 2000 Hz. Engdahl (1996) reported that there was no effect on exercise alone on auditory thresholds or DPOAE levels. Further, physical exercise significantly exacerbated the effect of noise on TTS and DPOAE levels. That is, auditory thresholds were significantly poorer and DPOAE levels significantly more depressed in the combined noise and exercise condition relative to the noise-alone condition.

The purpose of the present study was to examine further the effects of physical exercise and noise individually and simultaneously on TTS. Changes in auditory threshold and DPOAE levels were evaluated following experimental conditions. The additional effects of gender and ear were also explored.

METHOD

Participants

Eight normal-hearing young adult males (mean = 24.5 years, SD = 2.3) and eight normal-hearing females (mean = 23.0 years, SD = 0.8) participated. Normal hearing sensitivity was defined as pure-tone threshold sensitivity equal to or better than 25 dB HL. Participants also had normal middle ear function by immittance audiometry. Further, participants were ambulatory and in good health. General health status and physical fitness were assessed by the Body Mass Index (National Institutes of Health, 1998) and the PA-R "Self-Reported Physical Activity" (Jackson et al, 1990). All participants presented with a normal Body Mass Index and functional aerobic capacity. In addition, all participants presented with age-appropriate blood pressure and resting heart rate values (American Heart Association, 1999).

Apparatus

A double-walled, sound-treated audiometric test room (Industrial Acoustics Corporation), meeting specifications for permissible ambient noise (American National Standards Institute, 1999), served as the test environment. Four pure-tone signals (i.e., 2000, 3000, 4000, and 6000 Hz), generated by a clinical audiometer (Grason-Stadler GSI 61 Model 1761-9780XXE), served as the test frequencies. A 105-dBA 2000-Hz narrowband noise generated by the same clinical audiometer was employed as the noise stimulus. Test stimuli were calibrated with a sound level meter (Brüel and Kjær model 2231), pressure condenser microphone (Brüel and Kjær model 4144), and filter set (Brüel and Kjær model 1625). An insert earphone (Ear Tone model 3A) delivered the test stimuli.

DPOAEs were measured with a Grason-Stadler GSI-60 DPOAE system (Version 4.2.0) interfaced with a personal computer (Compaq model Deskpro 2000). Primary tones with an f_2/f_1 ratio of 1.2 were used to evoke DPOAEs. Twenty primary tone pairs with f_2 frequencies ranging from 2406 to 4625 were employed (i.e., 2406, 2468, 2562, 2656, 2750, 2843, 2968, 3062, 3156, 3281, 3406, 3500, 3625, 3750, 3906, 4031, 4187, 4312, 4468, and 4625). This frequency extent was selected because noise-induced changes in hearing sensitivity, as reflected in DPOAE measurements, are most often observed in this range (Engdahl, 1996). L_1 and L_2 primary levels employed to evoke the DPOAEs were 55 and 40 dB SPL, respectively. These values are most likely to show TTSs associated with noise exposure (Engdahl, 1996). A sequential signal presentation was used during DPOAE measures. DPOAE data were averaged in the time domain. Ten averages were obtained on each data point. Sampling rate was 24,000 Hz for all conditions.

Frame rejection occurred if the ambient noise level exceeded 30 dB SPL or if L_1 or L_2 was out of tolerance by ±5 dB. Test termination occurred if the test time exceeded 32 seconds or 1500 frames, if frame rejection occurred 50 times due to excessive ambient noise, or if frame rejection occurred 20 times due to L_1 or L_2 being out of tolerance for at least 20 frames. The test was accepted when at least 10 frames were averaged, the average noise level was less than –6 dB SPL, and either the DPOAE was 10 dB above the noise floor or the absolute noise level was less than −12 dB SPL.

A bicycle ergometer (Monark model 818E) was used in the conditions requiring exercise. In these conditions, a cardiotachometer (Polar model Accurex Plus) was used to monitor participants' heart rate. Room temperature was maintained in all experimental conditions at approximately 20 to 22°C.

Procedure

Participants were randomly assigned to have either the right or left ear serve as the test ear. Equal representations of right and left ears were tested for both genders. All participants were exposed to all experimental conditions on 4 different days each separated by 48 hours. During each test session, auditory thresholds and DPOAEs were assessed prior to and following each experimental condition. The order of threshold testing and DPOAE assessment was counterbalanced across participants. Auditory thresholds determined at four frequencies (i.e., 2000, 3000, 4000, and 6000 Hz) were obtained using the procedure recommended by the American Speech-Language-Hearing Association (1978). The presentation orders of experimental conditions and the four threshold frequencies conditions were determined by a digram-balanced Latin square (Wagenaar, 1969).

Following initial auditory threshold and DPOAE assessment, participants were exposed to 10 minutes of one of the four experimental conditions. In the quiet condition, participants engaged in quiet sedentary activity (e.g., reading). The exercise condition involved 10 minutes of bicycling on the stationary bike. With the heart monitor in place, participants were required to maintain 70 percent of their maximum heart rate during this condition. The test session began following a warm-up period of typically 2 to 4 minutes where participants reached this criterion. The noise condition entailed listening to 10 minutes of 2000-Hz narrowband noise presented monaurally while engaged in sedentary activity. The combined exercise and noise condition included 10 minutes of bicycling as described above with the same 10 minutes of noise exposure experienced in the noise-alone condition.

Subsequent to the experimental condition and following a 2-minute rest period, the retesting of auditory thresholds and DPOAE levels was undertaken. A second examiner who was unaware of the initial test results performed the retests. Signed differences in auditory threshold and DPOAE level were calculated by subtracting the pre- from the postexperimental condition values. Positive and negative differences reflected decreases and increases, respectively, in auditory thresholds and DPOAE levels.

RESULTS

Separate four-factor mixed analyses of variance were performed to investigate differ-

Table 1 Summary Table for the Four-Factor Mixed Analysis of Variance Investigating Mean Auditory Threshold Differences as a Function of Ear, Gender, Experimental Condition, and Frequency

Source	*df*	*F*	*p*	ω^2	ϕ
Ear	1	.029	.87	.00	.049
Gender	1	.18	.68	.00	.064
Ear × gender	12	1.84	.20	.007	.24
Experimental condition	3	92.58	*<.0001	.85	1.0
Experimental condition × ear	3	.59	.57	.00	.6
Experimental condition × gender	3	1.37	.27	.003	.33
Experimental condition × ear × gender	3	.88	.43	.00	.22
Frequency	3	4.22	.*018	.17	.82
Frequency × ear	3	.47	.67	.00	.4
Frequency × gender	3	1.13	.35	.007	.28
Frequency × ear × gender	3	.97	.41	.00	.24
Experimental condition × frequency	9	3.68	*.010	.12	.99
Experimental condition × frequency × ear	9	1.96	.11	.045	.82
Experimental condition × frequency × gender	9	2.05	.10	.049	.84
Experimental condition × frequency × ear × gender	9	1.69	.17	.032	.75

*p < .05; repeated-measures factor p values following a Geisser-Greenhouse correction; effect size indexed by ω^2 and power indexed by ϕ at α of .05.

Table 2 Summary Table for the Four-Factor Mixed Analysis of Variance Investigating Mean DPOAE Level Difference as a Function of Ear, Gender, Experimental Condition, and f_2 Frequency

Source	*df*	*F*	*p*	ω^2	ϕ
Ear	1	4.34	.059	.026	.48
Gender	1	1.77	.21	.006	.23
Ear × gender	12	.099	.76	.00	.057
Experimental condition	3	26.95	*<.0001	.63	1.0
Experimental condition × ear	3	1.04	.38	.001	.26
Experimental condition × gender	3	.79	.49	.00	.20
Experimental condition × ear × gender	3	.06	.96	.00	.061
Frequency	19	.80	.57	.00	.60
Frequency × ear	19	1.02	.42	.001	.73
Frequency × gender	19	1.43	.21	.026	.90
Frequency × ear × gender	19	1.25	.29	.015	.84
Experimental condition × frequency	57	.79	.62	.00	.93
Experimental condition × frequency × ear	57	1.42	.19	.027	1.0
Experimental condition × frequency × gender	57	.66	.73	.00	.86
Experimental condition × frequency × ear × gender	57	.94	.49	.00	.97

*$p < .05$; repeated-measures factor p values following a Geisser-Greenhouse correction; effect size indexed by ω^2 and power indexed by ϕ at α of .05.

ences in auditory thresholds and DPOAE levels as a function of ear, gender, experimental condition, and test frequency. The results of these analyses are presented in Tables 1 and 2. Relative treatment magnitude sizes and statistical power are indexed in both tables by omega squared (ω^2) and phi (ϕ), respectively.

With respect to differences in auditory threshold, significant main effects of experimental condition and test frequency were observed. As well, an experimental condition by test frequency interaction was found. All other main effects and interactions were not significant. The experimental condition by test frequency interaction is displayed in Figure 1. A number of single-df comparisons (Keppel and Zedeck, 1989; Keppel, 1991) were undertaken to assess further the interaction of experimental condition and test frequency. Orthogonal single-df comparisons performed at each test frequency revealed that there were no significant differences between the quiet and exercise conditions or between the noise-alone and combined exercise and noise conditions. The noise-alone and combined exercise and noise conditions had significantly greater auditory threshold differences than the quiet and exercise conditions. In other words, participants displayed significant elevations in auditory thresholds (i.e., TTS) following the two conditions employing noise exposure. There were no differences in auditory threshold differences between the noise-alone and combined exercise and noise conditions at any test frequency. When comparing the auditory threshold differences between 2000 and 6000 Hz, a significant difference was noted in the combined exercise and noise condition but not in the noise-alone condition. Similarly, when comparing the auditory threshold differences between 3000 and 6000 Hz, a significant difference was noted in the noise-alone condition but not in the combined exercise and noise condition. In all other respects, there were no significant differences in the pattern of responses between those two test conditions.

As evident in Table 2, a significant main effect of experimental condition on DPOAE level differences was observed. All other main effects

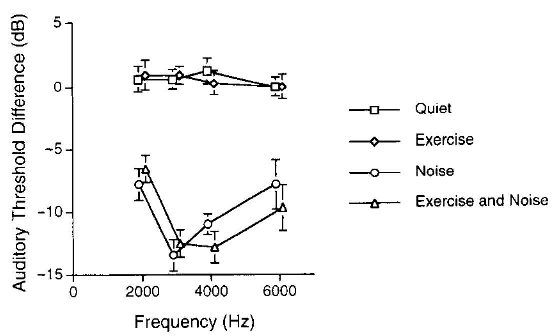

Figure 1 Mean auditory threshold differences as a function of experimental condition and test frequency. Error bars represent ±1 standard error of the mean. Positive and negative differences reflected decreases and increases, respectively, in auditory thresholds.

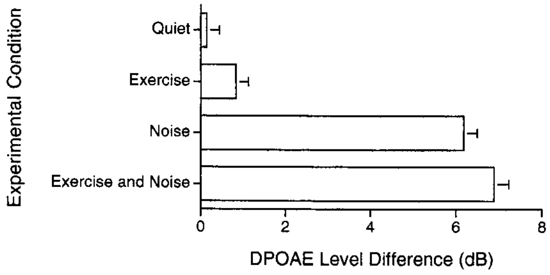

Figure 2 Mean DPOAE level differences as a function of experimental condition. Error bars represent +1 standard error of the mean. Positive differences reflected decreases in DPOAE levels.

and interactions were not significant. Figure 2 depicts the effect of experimental condition on DPOAE level differences across the f_2 frequency range. Orthogonal single-df comparisons were undertaken to examine the main effect of experimental condition. There were no significant differences between the quiet and exercise conditions or between the noise-alone and the combined exercise and noise conditions. The noise-alone and combined exercise and noise conditions resulted in significantly greater DPOAE level differences than the quiet and exercise conditions. In other words, participants displayed a significant reduction in DPOAE levels following the two conditions employing noise exposure.

DISCUSSION

The findings of the present study suggest that exposure to noise had a significant effect on auditory threshold and DPOAE level differences. That is, participants displayed, on average, significant elevations in auditory thresholds of 6 to 13 dB and decreases of 6 to 7 dB in DPOAE levels in the two conditions where participants were exposed to noise versus the two conditions of no-noise exposure. Exercise in combination with noise did not significantly exacerbate TTS or decrease DPOAE levels relative to noise exposure alone. No significant differences in auditory threshold or DPOAE level differences between the quiet and exercise conditions were found. Further, there were no effects of gender or ear on auditory threshold and DPOAE level differences following any experimental condition.

A failure to find a significant increase in noise-induced TTS with exercise is in agreement with previous findings (Dengerink et al, 1987; Hutchinson et al, 1991; Alessio and Hutchinson, 1992; Manson et al, 1994; Mirbod et al, 1994). A failure to observe a synergistic combination of exercise and noise on TTS as reported previously (Lindgren and Axelsson, 1988; Colletti et al, 1991; Vittitow et al, 1994; Engdahl, 1996) may be attributed to differences in methodology and participant selection. That is, physical workload definition, noise exposure duration and type, and level of physical fitness among participants varied between studies. Further, the greatest TTS evidenced was approximately ½-octave above the noise stimulus (i.e., 3000 to 4000 Hz) consistent with previous findings (Ward, 1973; Melnick, 1978). These findings contradict those of Miani et al (1986), who found that exercise alone induced TTS. With regard to DPOAE level changes, these findings are also in disagreement with Engdahl (1996), who reported that physical exercise increased noise-induced decreases in DPOAE level. Further, there was no evidence that the reduction of DPOAE level was greatest approximately ½-octave above the center frequency of the noise (cf., Engdahl and Kemp, 1996). That is, the study failed to find a significant test frequency effect on test–retest differences in DPOAE level.

This study also failed to find a significant effect of gender on TTS. Seminal studies by Ward (1966, 1973) suggest that gender differences in TTS are frequency dependent. That is, males show greater TTS for low-frequency stimuli (i.e., less than 1000 Hz) and significantly less at higher frequencies (i.e., greater than 2800 Hz). Interestingly, TTS for exposure to stimuli around 2000 Hz was reported by Ward to be the same between the two genders. In addition, Chermak and Dengerink (1987) failed to observe a significant gender effect on TTS measured at 2000 Hz. The findings of this study are consistent with these studies in failing to find a gender effect on TTS when a 2000-Hz stimulus is employed during noise exposure. It is also the case that ovarian and contraceptive cycles may play an additional role in TTS shift in females (Petiot and Parrot, 1984; Hori et al, 1993); however, this factor was not controlled in the present study.

A failure to find an ear effect on TTS counters the findings of Pirilä (1991a, b), who reported greater TTS in the left ear among 28 young adult male and female participants. It may be that ear effects on TTS depend on the noise stimulus, duration of exposure, and monaural or binaural exposure. That is, Pirilä (1991a, b) had participants listen binaurally to a broadband noise for a maximum of 8 hours, and TTS was assessed at only 4000 Hz. The exposure to noise among the participants of this study was considerably less (i.e., 10 min) and consisted of monaural 2000-Hz narrowband noise exposure.

In summary, further investigations toward the role of exercise and noise on auditory function are warranted. The role of gender, ear, frequency, and variation in exposure conditions remains equivocal. Further study will help delineate variables that can be expected to have significant effects on TTS among groups of individuals with varying levels of physical fitness who are exposed to noise.

REFERENCES

Alessio HM, Hutchinson KM. (1992). Cardiovascular adjustments to high- and low-intensity exercise do not regulate temporary threshold shifts. *Scand Audiol* 21:163–172.

American Heart Association. (1999). *Heart and Stroke Facts*. Dallas: American Heart Association.

American National Standards Institute. (1999). *Permissible Ambient Noise Levels for Audiometric Test Rooms*. (ANSI S3.1-1999). New York: ANSI.

American Speech-Language-Hearing Association. (1978). Guidelines for manual pure-tone threshold audiometry. *ASHA* 20:297–300.

Attias J, Bresloff I. (1996). Noise induced temporary otoacoustic emission shifts. *J Basic Clin Physiol Pharmacol* 7:221–233.

Attias J, Bresloff I, Reshef I, Horowitz G, Furman V. (1998). Evaluating noise induced hearing loss with distortion product otoacoustic emissions. *Br J Audiol* 32:39–46.

Barrenas ML, Lindgren F. (1991). The influence of eye colour on susceptibility to TTS in humans. *Br J Audiol* 25:303–307.

Bartsch R, Brückner C, Dieroff HG. (1986). Influence of different kinds of noise on the ear and some physiological and psychological parameters. *Int Arch Occup Environ Health* 58:217–226.

Borg E. (1968). A quantitative study of the effect of the acoustic stapedius reflex on sound transmission through the middle ear of man. *Acta Otolaryngol (Stockh)* 66:461–472.

Chermak GD, Dengerink JE. (1987). Characteristics of temporary noise-induced tinnitus in male and female subjects. *Scand Audiol* 16:67–73.

Colletti V, Fiorino RG, Verlato G, Montresor G. (1991). Reduced active protection to the cochlea during physical exercise. *Acta Otolaryngol (Stockh)* 111:234–239.

Cunningham DR, Norris ML. (1982). Eye color and noise-induced hearing loss: a population study. *Ear Hear* 3:211–214.

Delb W, Hoppe U, Liebel J, Iro H. (1999). Determination of acute noise effects using distortion product otoacoustic emissions. *Scand Audiol* 28:67–76.

Dengerink HA, Trueblood GW, Dengerink JE. (1984). The effects of smoking and environmental temperature on temporary threshold shifts. *Audiology* 23:401–410.

Dengerink HA, Lindgren F, Axelsson A, Dengerink JE. (1987). The effects of smoking and physical exercise on temporary threshold shift. *Scand Audiol* 16:131–136.

Drettner B, Hedstrand H, Klockhoff I, Svedberg A. (1975). Cardiovascular risk factors and hearing loss. A study of 1000 fifty-year-old men. *Acta Otolaryngol (Stockh)* 79:366–371.

Engdahl B. (1996). Effects of noise and exercise on distortion product otoacoustic emissions. *Hear Res* 93:72–82.

Engdahl B, Kemp DT. (1996). The effect of noise exposure on the details of distortion product otoacoustic emissions in humans. *J Acoust Soc Am* 99:1573–1587.

Gerhardt KJ, Rodriguez GP, Hepler EL, Moul ML. (1987). Ear canal volume and variability in the patterns of temporary threshold shifts. *Ear Hear* 8:316–321.

Hood JD, Poole JP, Freedman L. (1976). The influence of eye colour upon temporary threshold shift. *Audiology* 15:449–464.

Hori C, Nakashima K, Sato H. (1993). A study of sex differences in temporary threshold shift (TTS) considering the menstrual cycle of women. *J Hum Ergol* 22:131–139.

Humes LE. (1984). Noise-induced hearing loss as influenced by other agents and by some physical characteristics of the individual. *J Acoust Soc Am* 76:1318–1329.

Hutchinson KM, Alessio HM, Spadafore M, Adair RC. (1991). Effects of low-intensity exercise and noise exposure on temporary threshold shift. *Scand Audiol* 20:121–127.

Jackson AS, Blair SN, Mahar MT, Wier LT, Ross RM, Stuteville JE. (1990). Prediction of functional aerobic capacity without exercise testing. *Med Sci Sports Exerc* 22:863–870.

Keppel G. (1991). *Design and Analysis: A Researcher's Handbook*. 3rd Ed. Englewood Cliffs, NJ: Prentice Hall.

Keppel G, Zedeck Z. (1989). *Data Analysis For Research Designs*. New York: WH Freeman.

Kolkhorst FW, Smaldino JJ, Wolf SC, Battani LR, Plakke BL, Huddleston S, Hensley LD. (1998). Influence of fitness on susceptibility to noise-induced temporary threshold shift. *Med Sci Sports Exerc* 30:289–293.

Lindgren F, Axelsson A. (1983). Temporary threshold shift after exposure to noise and music of equal energy. *Ear Hear* 4:197–202.

Lindgren F, Axelsson A. (1988). The influence of physical exercise on susceptibility to noise-induced temporary threshold shift. *Scand Audiol* 17:11–17.

Manson J, Alessio HM, Cristell M, Hutchinson KM. (1994). Does cardiovascular health mediate hearing ability? *Med Sci Sports Exerc* 26:866–871.

Melnick W. (1978). Temporary and permanent threshold shift. In: Lipscomb DM, ed. *Noise and Audiology*. Baltimore: University Park Press, 83–107.

Miani C, Bertino G, Francescato MP, di Prampero PE, Staffieri A. (1996). Temporary threshold shift induced by physical exercise. *Scand Audiol* 25:179–186.

Mirbod SM, Lanphere C, Fujita S, Komura Y, Inaba R, Iwata H. (1994). Noise in aerobic facilities. *Industrial Health* 32:49–55.

National Institutes of Health. (1998). *Clinical Guidelines on the Identification, Evaluation, and Treatment of Overweight and Obesity in Adults. The Evidence Report.* NIH Publication No. 98-4083. Washington, DC: US Government Printing Office.

Petiot JC, Parrot JE. (1984). Effects of ovarian and contraceptive cycles on absolute thresholds, auditory fatigue and recovery from temporary threshold shifts at 4 and 6 kHz. *Audiology* 23:581–598.

Pirilä T. (1991a). Left-right asymmetry in the human response to experimental noise exposure. I. Interaural correlation of the temporary threshold at 4 kHz frequency. *Acta Otolaryngol (Stockh)* 111:677–683.

Pirilä T. (1991b). Left-right asymmetry in the human response to experimental noise exposure. II. Pre-exposure hearing threshold and temporary threshold shift at 4 kHz frequency. *Acta Otolaryngol (Stockh)* 111:861–866.

Sandén Å, Axelsson A. (1981). Comparison of cardiovascular responses in noise-resistant and noise-sensitive workers. *Acta Otolaryngol Suppl (Stockh)* 377:75–100.

Swanson SJ, Dengerink HA, Kondrick P, Miller CL. (1987). The influence of subjective factors on temporary threshold shifts after exposure to music and noise of equal energy. *Ear Hear* 8:228–291.

Vittitow M, Windmill IM, Yates JW, Cunningham DR. (1994). Effect of simultaneous exercise and noise exposure (music) on hearing. *J Am Acad Audiol* 5:343–348.

Wagenaar WA. (1969). Note on the construction of digram-balanced Latin squares. *Psychol Bull* 72:384–386.

Ward WD. (1966). Temporary threshold shift in males and females. *J Acoust Soc Am* 40:478–485.

Ward WD. (1973). Adaptation and fatigue. In: Jerger J, ed. *Modern Developments in Audiology*. 2nd Ed. New York: Academic, 301–344.

Zelman S. (1973). Correlation of smoking history with hearing loss. *JAMA* 223:920.