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Effect of low level acoustic stimulation on temporary threshold shift in young humans

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To assess the effect of a low level acoustic stimulation on the susceptibility to noise, young human subjects were exposed to music at 70 dBA for 6 h per day during 9 days (training period). Noise sensitivity was assessed by measuring temporary threshold shift (TTS) induced by 105 dBSPL, 1/3 octave band noise at 2 kHz for 10 min. On the fifth day of the training period, a significant decrease of TTS was observed in the frequency range 3–3.5 kHz, in comparison with the baseline TTS obtained before being trained. As the training continued, the frequency range which showed a significant reduction of TTS expanded to 2–5 kHz.

Noise induced hearing loss; Temporary threshold shift; Susceptibility; Training; Motility

Introduction

The existence of large individual differences in noise susceptibility has made it difficult to understand the basic mechanisms of noise-induced hearing loss (NIHL) and to implement hearing conservation programs effectively in the noisy workplace (Møller, 1980; Sandén and Axelsson, 1981). In addition, in order to elucidate the mechanisms of temporary threshold shift (TTS) and permanent threshold shift (PTS), it is important to understand possible interactions between noise and other variables, e.g., the individual variation of sound transfer function in the external auditory canal (Hellström, 1992), and the function of middle ear muscles (Miyakita et al., 1980; Borg and Nilsson, 1984) and various environmental factors such as vibration (Miyakita et al., 1987; Hamernik et al., 1989) and ambient temperature (Henry and Chole, 1984), etc.

Recent studies have suggested that previous exposure to a low level acoustic stimulus could reduce the damaging effects caused by subsequent exposure to the same stimulus at high intensity (Canlon et al., 1988, 1991; Henderson et al., 1991a,b). Canlon et al. (1988) exposed guinea pigs to a 1 kHz pure tone at 81 dB for 21 days and then exposed the subjects to the same tone at 105 dB for 48 h. This pre-exposure resulted in approximately 20 dB reduction in the threshold shift relative to animals not pre-exposed, and complete recovery from the threshold shift after 2 months, when the not pre-exposed animals still showed hearing loss. Furthermore, they confirmed the same phenomenon in the rabbit (Canlon et al., 1991). Henderson et al. (1991a) exposed chinchillas to an octave band noise at 0.5 kHz at 95 dB for ten days (6 h/day) and then allowed the animals to recover for five days. On the sixteenth day the subjcts were again exposed to the same noise at 106 dB for 48 h. In comparison with the results of a control group consisting of animals with no previous exposure, they concluded that previous exposure to non-traumatic noise does render the animals less susceptible to damage from traumatic exposure. Recently, Ryan et al. (1992) also confirmed that threshould shift produced by a 100 dBSPL two octave-band noise (1414-5656 Hz) was reduced in gerbils previously exposed to the same noise at 81 dB SPL, but only on the side in which the middle ear muscles had been sectioned.

In the present study we investigated whether this phenomenon, the so called 'training' effect (Canlon et al., 1988) or development of 'resistance' (Henderson et al., 1991a) can be demonstrated in human subjects.

Materials and Methods

The experimental subjects were 12 teenage volunteers (8 females and 4 males) with a mean age of 13.6 years (range: 12 to 16). Each individual showed normal hearing (< 20 dBHL at all test frequencies) in the

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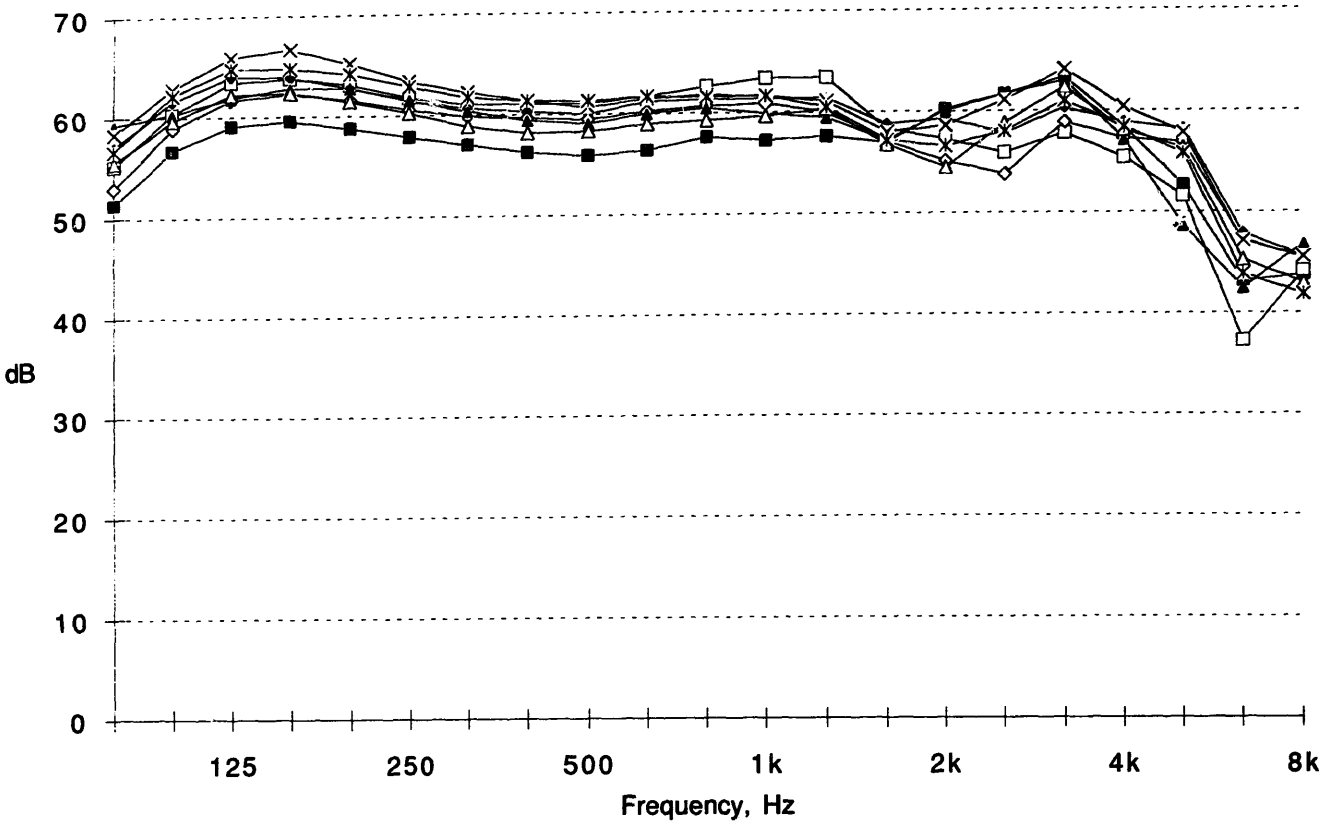

Fig. 1. One-third octave band SPLs of the training music in each subject's ear averaged for 68 min.

frequency range 0.8 to 8 kHz (TELTEC CA90pc with TDH 39 headphones in MX41/AR cushions). Middle ear pressures were within 0 ± 0.25 kPa for all subjects confirmed by tympanometry using impedance audiometry (GSI 33) with a 226 Hz probe tone.

The experimental noise consisted of a 1/3 octave band filtered noise with a center frequency at 2 kHz. In order to minimize variations caused by headphone placement, the exposure noise was delivered to the subjects via an insert earphone (ER-3A). As a training stimulus, we prepared music tapes for each subject comprising 15 pieces of pop/rock music with a mean duration of 274 s (range = 216 to 387) which was replayed 5–6 times, in total 6 h. The tape was played

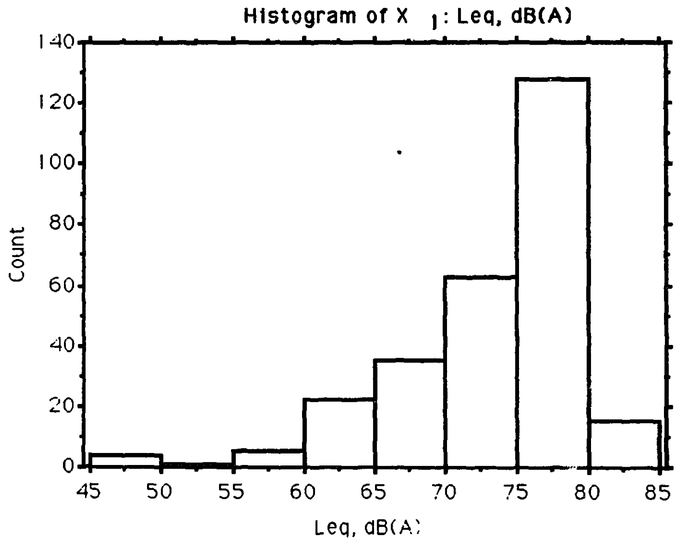

Fig. 2. Frequency histogram of Leq values measured every 15 s. The 273 readings made for 68 min.

with a cassette player (SONY WM-EX10) and stereo earphones (SONY MDR, E565). The intensity was adjusted to around 70 dBA equivalent sound pressure level (Leq). No significant TTS could be detected in any subject at this level. The level was monitored during the 68 min tape duration using a real-time analyser (Norwegian Electronics type 830) and a probe tube mini-microphone (KNOWLES EA 1842) inserted in the external auditory canal with the probe opening situated 1–3 mm from the tympanic membrane and the microphone itself placed between the headphone and the entrance of the ear canal (Hellström and Axelsson, 1991). The results of a 1/3 octave band analysis of the music tape used during the training period for 8 subjects is shown in Fig. 1. Total Leqs of the whole tape (68 min) measured in each subject showed a range of 69.4 to 72.0 dBA. Fig. 2 shows the frequency histogram of Leq values measured during every 15 s in one subject. Leq values ranged from 46.0 to 82.5 dBA during 68 min.

Hearing thresholds were determined by a computerized sweep-frequency audiometer (type Bekesy) in the frequency range 0.8 to 8 kHz (Lindgren and Axelsson, 1986). The post-exposure pure tone threshold determination started at 800 Hz 20 s after cessation of the exposure. The computerized evaluation of the sweep recordings made it possible to calculate a mean hearing level over an arbitrary range of frequencies (1–2, 2–2.5, 2.5–3, 3–3.5, 4–5 and 5–6 kHz). The TTS was calculated as the difference in dB between pre- and post-exposure thresholds at above given areas. All hearing tests were carried out in a sound-proof booth, with background sound pressure levels below those recommended by ISO-8253 (1989). The audiometers were regularly calibrated in accordance with ISO-389 (1985). All hearing tests and noise exposures were conducted by the same audiometric technician at all sessions.

A single experiment consisted of 3 weeks divided into 4 periods (Fig. 3):

a) 4 days of pre-training, day 1–4 (D1–D4)
b) 9 days of training, D5–D13
c) 3 day break, D14–D16
d) 5 days of post-training, D17–D21.

During the experimental days, except on D14, D15 and D16, the subject's hearing thresholds were tested twice a day when they were not exposed to the experimental noise; once in the morning and again 6 h later after listening to the music during the training period or after wearing ear plugs during the post-training period.

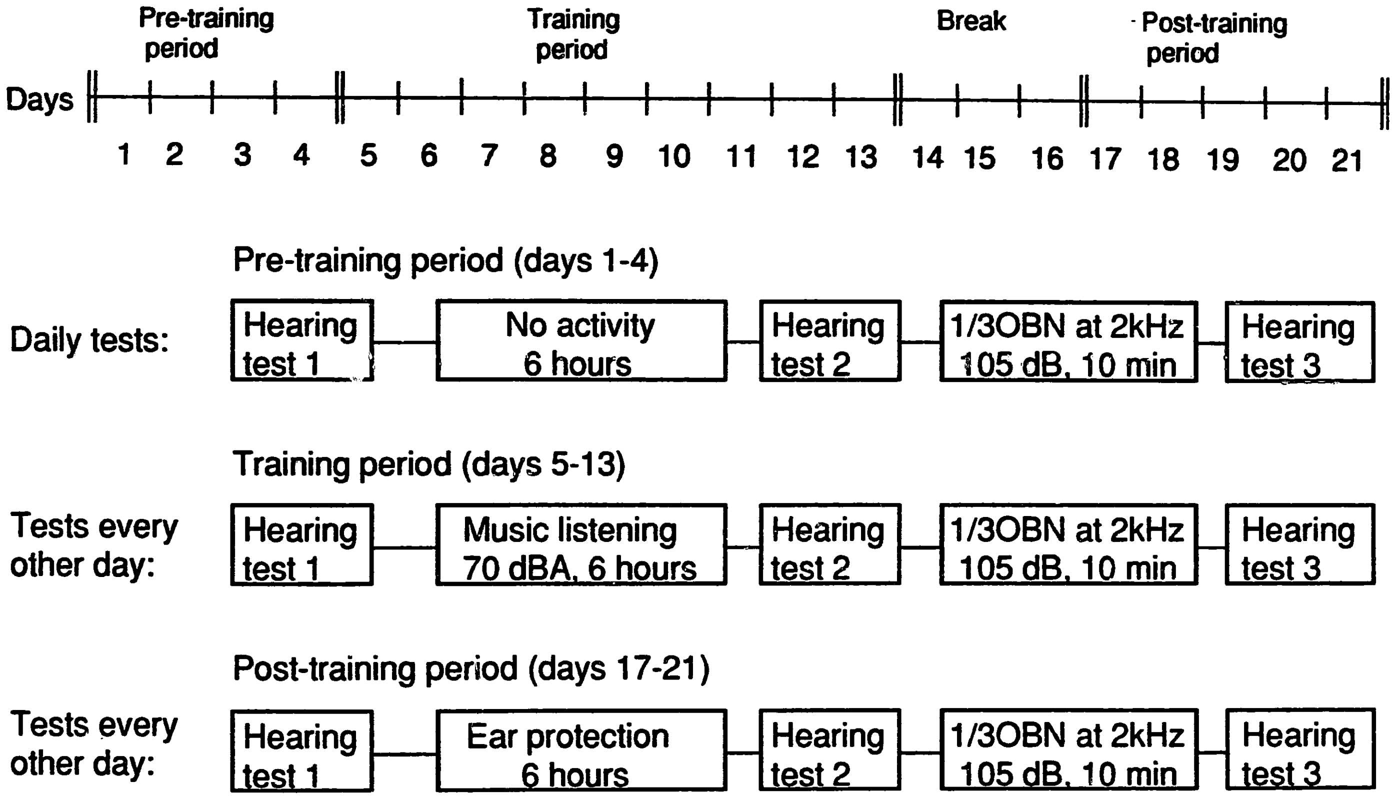

Fig. 3. Schematic representation of the experimental condition in the pre-training, training and post-training period. During the training and post-training period, subjects were exposed to traumatic noise every other day. Three days break was inserted between the training and post-training periods.

On the days when they were exposed to noise, the third test was conducted just after the 10 min exposure to noise.

During the 3 day break, the subjects were instructed to avoid noisy environments. During the pre-training period, the aim was to determine the amount of TTS caused by noise. The subjects were exposed to a 1/3 octave band 2 kHz noise at 105 dBSPL for 10 min, once a day. The result from the first day was discarded since it was considered a pre-training test to make the subjects familiar with the testing procedure. The average of the three other measures constituted the pre-training TTS for a given subject and served as a baseline (BL) value with which the results during and after training were compared. During the second period (training period), the subjects were exposed to music 6 h per day for 9 days. Hearing thresholds were monitored each day just before and after the training exposure to check whether the music caused any significant TTS. On D5, D7, D9, D11 and D13 of this period, after 6 h training and hearing tests, subjects were exposed to noise for 10 min and tested again just after the exposure.

During the forth period (post-training period), the subjects were instructed to wear ear plugs (EAR® Yellow) in both ears 6 h each day, and the amount of TTS from the experimental noise exposure was determined again, every other day (on D17, D19 and D21). The statistical significance of the differences between means were determined with a two tailed Student's *t*-test.

Results

Of 12 young volunteers, 4 subjects had difficulties with consistency using Bekesy audiometry. Therefore, these 4 subjects were excluded from the study and the analysis was conducted on 8 subjects (6 females and 2 males) with a mean age of 13.5 years (range: 12–16).

The difference in mean hearing levels before and after listening to training music on D5, D7, D9, D11 and D13 during the training period was not statistically significant in any frequency range ($P > 0.05$, Students' *t*-test).

Fig. 4 shows the changes in mean TTS of 8 subjects during the pre-training and training period. The baseline curve showed 11.0, 15.5, 15.1, 14.1 and 12.0 dB of TTS in the frequency range 2–2.5, 2.5–3, 3–3.5, 3.5–4 and 4–5 kHz, respectively. The amount of TTS on the first and third day of the training period (D5 and D7) was almost equivalent to the BL values. As the training continued, significant decreases of TTS were observed on D9, D11 and D13, i.e. on and after 5 days of

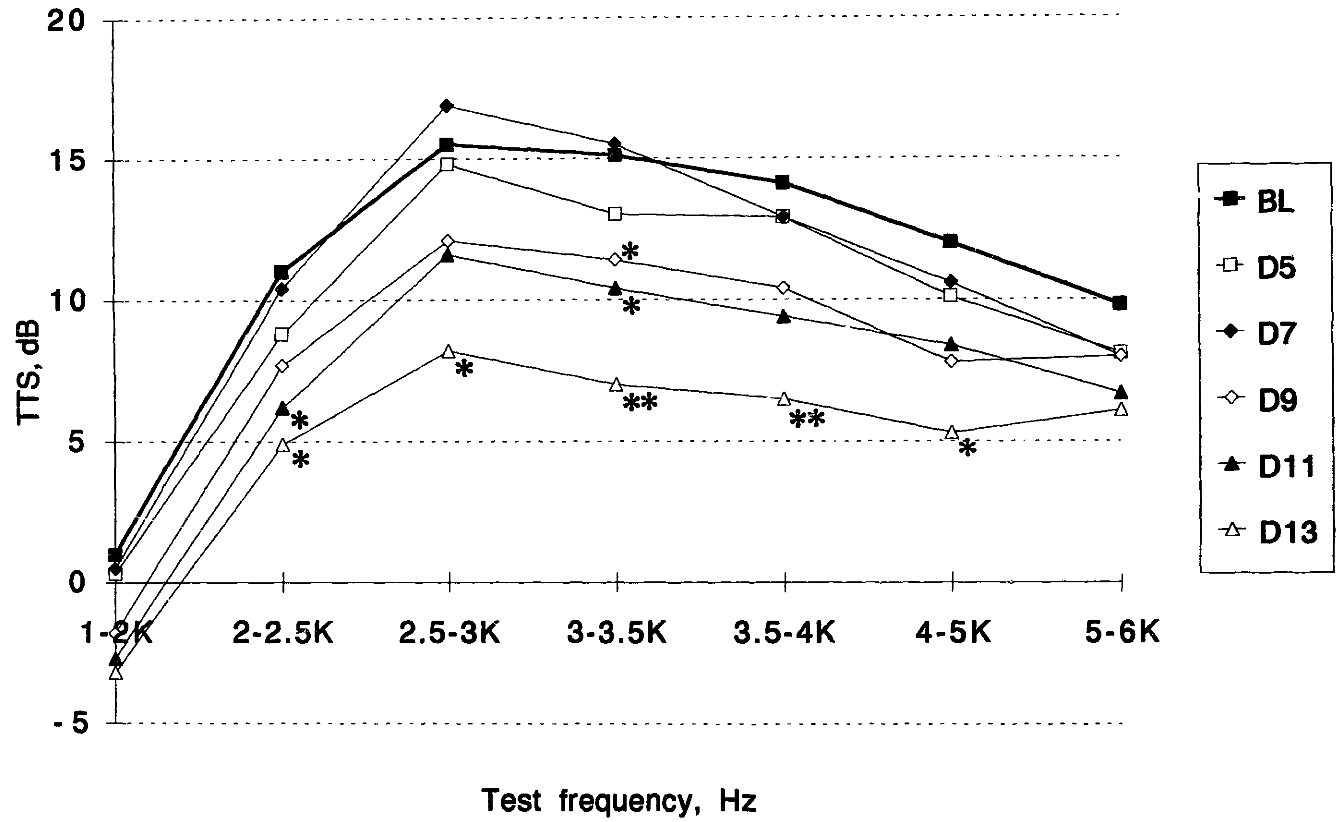

Fig. 4. Changes in mean TTS of 8 subjects caused by 105 dBSPL, 1/3 octave band noise with a center frequency of 2 kHz during training period together with the base line (BL) curve obtained in the pre-training period. * $P < 0.05$, ** $P < 0.01$ (BL vs D9, D11 and D13).

training. In the frequency range 3–3.5 kHz, the TTS compared with the BL values decreased as follows: 3.7 dB (D9), 4.7 dB (D11) and 8.1 dB (D13) which corresponds to 25%, 31% and 54% of reduction. These decreases were all statistically significant ($P < 0.05$). On D9, only the frequency range 3–3.5 kHz showed significant decrease of TTS, but on D13 a significant decrease was observed in a wide frequency range at 2–5 kHz.

The changes in mean TTS for the 8 subjects during the post-training period together with the BL curve and the curve obtained on D13, i.e. the last day of the training period, are shown in Fig. 5. On D17 and D19, 4 and 6 days after cessation of training, TTS increased significantly in a wide frequency range and approached the base line values. When D17 was compared to D13, 6.1 dB and 4.9 dB of significant TTS increases ($P <$ 0.05) were observed in the frequency range 2.5–3 and 3.5–4 kHz. There was little additional increase of TTS in the range 3–4 kHz on D19. However, TTS decreased again on D21, especially in the high frequency range 3–5 kHz, although differences between the baseline curve and the one on D21 were not statistically significant. On the other hand, when D21 was compared to D13, 5.0 and 3.8 dB of differences in the frequency range 2.5–3 and 3–3.5 kHz neither were statistically significant ($P > 0.05$). Four subjects were retested 2 months after D21. They showed same amount of TTS as BL values.

Discussion

The major finding of this study was that young human subjects exposed to a training stimulus at 70 dBA 6 h per day for 9 days developed some resistance to noise during the training period. Compared with the baseline TTS obtained from the pre-training period, a significant TTS decrease was observed in the frequency range 3–3.5 kHz on and after D9 when the subjects have had five days of training, 30 h in total. As the training continued, the frequency range which showed a significant reduction of TTS was expanded to 2–5 kHz. Although the amount of TTS decrease was not so large as previously reported in animal studies (Canlon et al., 1988, 1991; Henderson et al., 1991a,b), our findings indicate the need of further studies.

When we design an experimental study which aims to evaluate the effects of a low level stimulus on TTS, there are at least three important factors to be considered; which may modify the results both qualitatively and quantitatively. First, the training stimulus which is expected to cause some changes in susceptibility to noise exposure; secondly, the noise which may produce

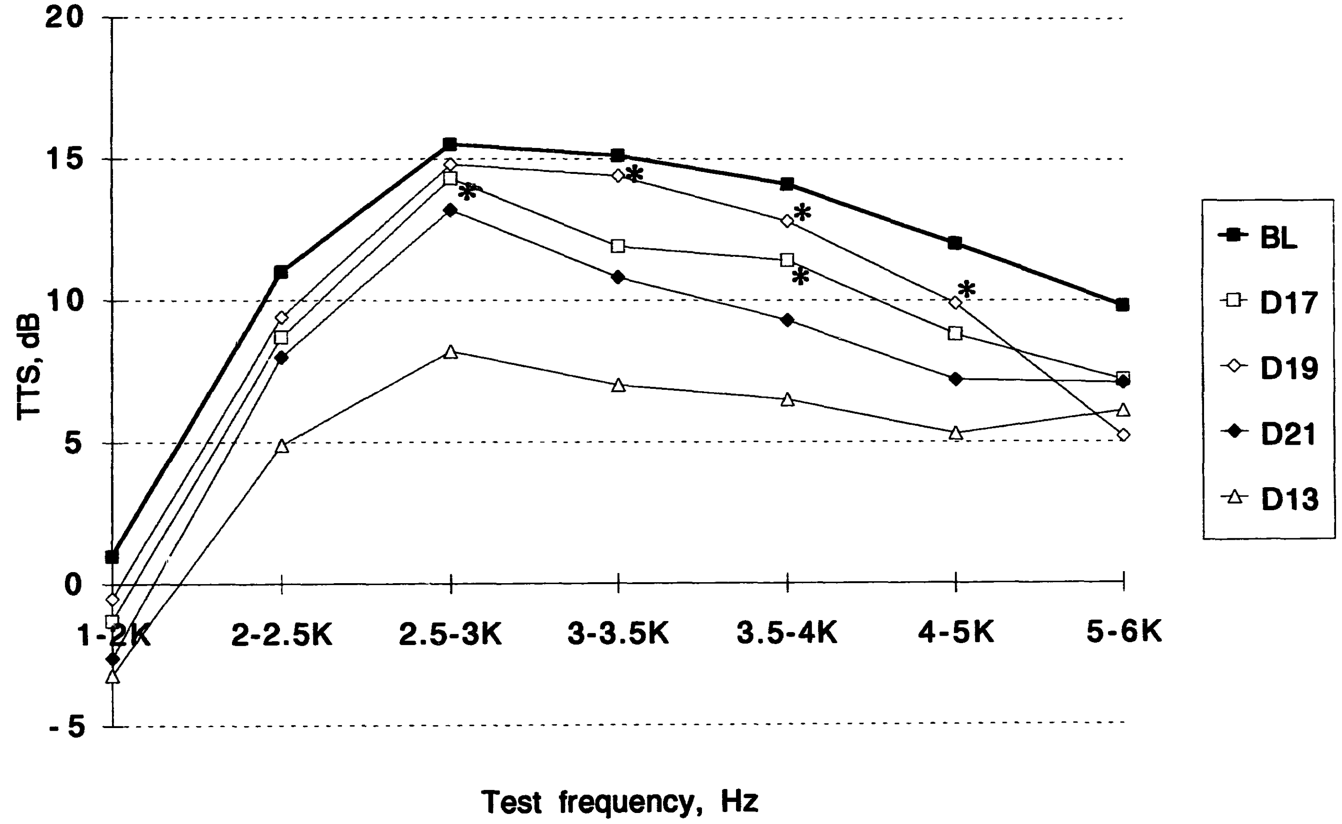

Fig. 5. Changes in mean TTS of 8 subjects during post-training period together with the base line curve and the curve obtained on D13, i.e. the last day of the training period. * P < 0.05 (D13 vs D17, D19).

reversible changes in hearing thresholds with a certain variation among subjects; and thirdly, the experimental time schedule. As to the training stimulus, matters such as frequency characteristics, listening level, training hours per day and total training period come into question. Careful considerations are required to protect each subject's hearing. Various experimental conditions used in previous studies concerning a 'training' effect and the present study are summarized in Table I.

Although the exact time course of a possible maximum training effect is unkwown, our subjects showed significant decrease of TTS on and after the fifth day of training, which is relatively shorter than similar periods reported in previous investigations (Canlon et al., 1991; Henderson et al., 1991a,b). This training effect almost disappeared four days after the last day of training. It seemed that the training effect observed under the experimental conditions used in this study was not persistent. During the three days break between the training and post-training periods, subjects were instructed to avoid noisy environments. Canlon et al. (1991), however, maintained rabbits in ambient noise for either 2 weeks or one month after being trained for 256 hours and then exposed them again to the high intensity stimulation and resistance against noise was still evident. This discrepancy might be due to the difference in length of the training period. The reduction of TTS observed on the last day of the post-training period shown in Fig. 4 suggests that a certain common mechanism might be re-triggered on D21 by 105 dBA, 1/3 octave band noise. If so, there is some possibility that the noise, to which the subjects were exposed every other day, might partly participate in the reducion of TTS during the training period. As reported by Clark et al. (1987), Henderson et al. (1991a,b) and Subramaniam et al. (1991), a repeated exposure with periodic rest develops some resistance to the traumatic noise, although it shows level and frequency dependency. Practically, it is rather difficult to evaluate these effects separately, but a consideration of these matters is needed for determinig the experimental design in future studies.

The underlying physiological mechanisms and the anatomical sites responsible for the reduction in noise susceptibility are as yet unknown, but recent advances in auditory physiology shed some light on them. Most of the morphological investigations have illustrated that the outer hair cells (OHCs) are more susceptible to noise trauma than the inner hair cells (IHCs) (Libscomb et al., 1977; Saunders et al., 1985) and OHCs have been considered to have a close connection with the physiologically sensitive but vulnerable process of sharp tuning (Liberman and Dodds, 1984; Pickles 1988). Further, the concept that OHCs possess an active motor capacity (Flock, 1988; Gelfand, 1990), i.e. OHCs act not only as passive mechanoelectrical transducers but also as electromechanical transducers, is very interesting for investigating the biological basis of the training effect observed in this study. Several new observations from the auditory system have supported the above concept, e.g. the so-called 'cochlear echoes' or 'evoked oto-acoustic emissions', first reported by Kemp (1978). While the exact mechanism of the cochlear echo is not understood, there is agreement that it is connected with active processes occurring inside the cochlea (Mountain, 1980; Siegel and Kim, 1982).

In the light of recent findings about active motor capacity of OHCs, Zenner (1986) suggested that OHCs may act so as to attain adaptation to high sound pressure and moreover to control the damping characteristics of the basilar membrane. If the change in susceptibility to noise observed in the present study has some connection with the changes of an active motor capacity of OHCs, to monitor the evoked oto-acoustic emissions and/or distortion product $(2f_2-f_1)$ in the

TABLE I

Various experimental conditions adopted in the previous studies concerning a training effect

	Training noise			Quiet interval	Traumatic noise			Threshold effect
	Frequency	Level	Duration		Frequency	Level	Duration	
Rajan et al. (1983) [1]	10 kHz PT	97 dBSPL	1 min	30 min	10 kHz tone	103 dBSPL	1 min	reduced TTS
Canlon et al. (1988) [2]	1 kHz PT	81 dBSPL	576 h	no	1 kHz tone	105 dBSPL	72 h	reduced TTS and PTS
Canlon et al. (1991) [3]	2–7 kHz BBN	79 dBSPL	256 h	no	2–4 kHz noise	131 dBSPL	15 min	reduced TTS and PTS
Henderson et al. (1991) [4]	OBN centered at 0.5 kHz	95 dBSPL	6 h/day 10 days	5 days	OBN centered at 0.5 kHz	106 dBSPL	48 h	reduced TTS and PTS
Henderson et al. (1991) [5]	OBN centered at 4 kHz	85 dBSPL	6 h/day 10 days	5 days	OBN centered at 4 kHz	100 dBSPL	48 h	increased PTS
	OBN centered at 4 kHz	85 dBSPL	6 h/day 10 days	18 h	OBN centered at 4 kHz	100 dBSPL	48 h	reduced PTS
Present study	Pop/Rock-music	70 dBA	6 h/day 9 days	no	1/3 OBN centered at 2 kHz	105 dBSPL	10 min	reduced TTS

[1,2] guinea pigs; [3] rabbits; [4,5] chinchillas. PT: pure tone, BBN: broad band noise, OBN: octave band noise.

course of developing resistance to noise remains to be elucidated.

It is a property of all sensory systems that exposure to a stimulus of sufficient duration and intensity produces changes in responsiveness. In general, the body responds in a sensitive and continuous manner to the environment. In the auditory system, two distinct phenomena known as per-stimulatory adaptation and post-stimulatory fatigue have been identified, although the differences in the physiological processes involved in these phenomena have not been elucidated. While the mechanism for the decrease of TTS demonstrated during the training period is unknown, development of resistance against noise might share common mechanisms with loudness adaptation and/or post-stimulatory fatigue. Whatever the mechanism in this case, the decrease of sensitivity induceded by noise training resulted in the reduced TTS. Further studies are needed to understand the underlying physiological mechanism for the training effect.

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