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ORIGINAL ARTICLE

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Combined effects of hand-arm vibration and noise on temporary threshold shifts of hearing in healthy subjects

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Abstract *Object*: To investigate whether hand-arm vibration and noise have a combined effect on temporary threshold shift (TTS) of hearing among healthy subjects. *Method and design*: Nineteen healthy subjects with an average age of 25.7 (SD 7.7) years were exposed to vibration (30 m/s^2, 60 Hz), noise [90 dB(A)] and both, respectively. The subject's right hand was placed on the plate of a vibrator and the right ear exposed to noise via headphones. Subjects were exposed to vibration and/or noise for 3 min and after a 1-min pause the exposure was repeated five times. Hearing thresholds at 1, 4 and 6 kHz were measured during the time periods before, between (during pauses) and after exposure. *Results*: Exposure to vibration alone caused almost no hearing threshold changes at every frequency tested. But exposure to noise or a combination of vibration and noise caused a significant increase in TTSs at 4 and 6 kHz. Moreover, exposure to a combination of vibration and noise caused significantly higher TTSs than exposure to noise at 4 and 6 kHz. *Conclusion*: The present results demonstrate the combined effects of hand-arm vibration and noise on hearing: simultaneous exposure to hand-arm vibration and noise can enhance the TTS of hearing more than noise exposure, though hand-arm vibration alone may hardly affect TTS.

Key words Combination of hand-arm vibration and noise · TTS of hearing · Sympathetic nervous activity

Introduction

It is well known that noise causes noise-induced permanent threshold shift (NIPTS) of hearing, while hand-arm vibration produces vibration-induced white finger (VWF). Workers operating vibrating tools are exposed to both hand-arm vibration and noise from the tools, and thereby risk developing NIPTS and VWF. Previous epidemiological studies indicated a positive link between NIPTS and VWF among operators: those with VWF had significantly greater NIPTS than those without VWF (Pyykkö et al. 1981; Iki et al. 1985; Miyakita et al. 1987a; Sakakibara and Yamada 1987). The results suggested that long-term exposure to hand-arm vibration might contribute to greater NIPTS, or hand-arm vibration and noise might have combined effects on hearing. However, these epidemiological studies did not prove this suggestion, because workers operating vibrating tools are simultaneously affected by both hand-arm vibration and noise from the tools. In addition, experimental studies on the combined effects of hand-arm vibration and noise on hearing are still too few to confirm that suggestion. The purpose of the present study was to provide an experimental basis from an epidemiological viewpoint by investigating whether hand-arm vibration causes a temporary threshold shift (TTS) of hearing, and whether a combination of hand-arm vibration and noise aggravates noise-induced TTS among healthy subjects.

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Materials and methods

Subjects were 19 healthy volunteers (14 males and 5 females) with an average age of 25.7 (SD 7.7) years (range 20–40 years). They had not been occupationally exposed to vibration and noise, and had not had any otitis, deafness, tinnitus, or other diseases. Prior to the experiment the study was explained to all subjects, who gave their informed consent on the basis of the principles in the Declaration of Helsinki.

The subjects participated in each of the following three randomly arranged tests: test 1 (vibration exposure), exposure only to vibration (30 m/s^2 rms, 60 Hz); test 2 (noise exposure), exposure only to noise [90 dB(A), white noise]; test 3 (combined exposure), exposure to both, vibration and noise.

There was an interval of more than 24 h between tests to avoid any effects from the previous test.

During each test, subjects sat on a chair with arm rests, and put their right hands on the plate of a vibrator while wearing headphones connected to an audiometer. Then, vibration (30 m/s^2, 60 Hz) produced by a vibrator (EMIC, E-1011A, Rikenonkyo, Nagoya, Japan) was applied to the right hand, while white noise of 90 dB(A), generated by an audiometer (Model MA22, Maico Hearing Instruments Inc., Minnesota, USA), was applied to the right ear via a headphone. The subject's left ear was covered by the same headset. Subjects were exposed to vibration and/or noise for 3 min and after a 1-min pause the same length exposure was repeated five times.

Hearing thresholds of the right ear at 1, 4, and 6 kHz were measured with the same audiometer used to generate noise. Prior to the first measurement of hearing thresholds, subjects underwent several trials to become familiar with the testing process. Then thresholds were measured 2 min before starting the first exposure. In each 1-min pause between exposures, the measurement started 10 s after cessation of exposure and finished within 30 s. Hearing thresholds were also measured at the first, second, third and fifth minute after cessation of the last exposure. The measurements of hearing thresholds were made by the same examiner.

Subjects wore street clothes during the experiments (which were conducted in May and July). Room temperature was kept between 22 and 25 °C with an air-conditioner. Background noise in the experiment room was less than 45 dB(A) when a vibrator was working nearby. Since subjects wore headphones throughout the experiments, such background noise did not affect the results.

TTS of hearing at each frequency was computed by subtracting the threshold before the first exposure from that obtained in pauses and recovery time. TTSs from exposure to vibration or noise or both were compared statistically using Wilcoxon matched-pairs signed-rank test.

Results

At 1 kHz hearing threshold, exposure to vibration, noise or both did not produce a significant increase in TTSs; mean TTSs were all less than 5 dB in every exposure (Fig. 1). TTSs from the combined exposure were greatest, and tended to be greater than TTSs in noise exposure alone, though there was no significant difference between them.

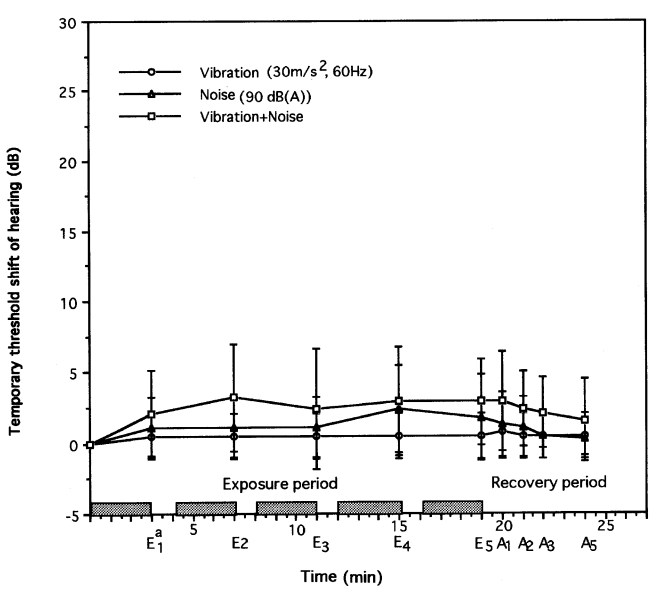

Fig. 1 Temporary threshold shift (TTS)(dB) at 1 kHz during and after exposure to vibration (30 m/s^2, 60 Hz) and/or noise [90 dB(A)] (n = 19). *a* E_1 to E_5 represent TTSs measured in pauses after the first to the fifth 3-min exposures, and A_1 to A_5 represent TTSs measured at 1, 2, 3, and 5 min after fifth exposure

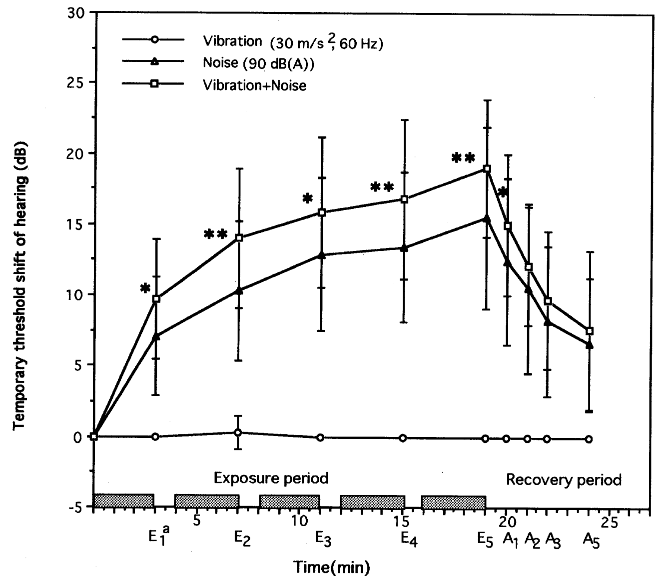

Fig. 2 TTS(dB) at 4 kHz during and after exposure to vibration (30 m/s^2, 60 Hz) and/or noise [90 dB(A)] (n = 19). *a* E_1 to E_5 represent TTSs measured in pauses after the first to the fifth 3-min exposures, and A_1 to A_5 represent TTSs measured at 1, 2, 3, and 5 min after fifth exposure. $*P < 0.05$; $**P < 0.01$, statistical difference by Wilcoxon matched-pairs signed rank test between noise exposure and combined exposure

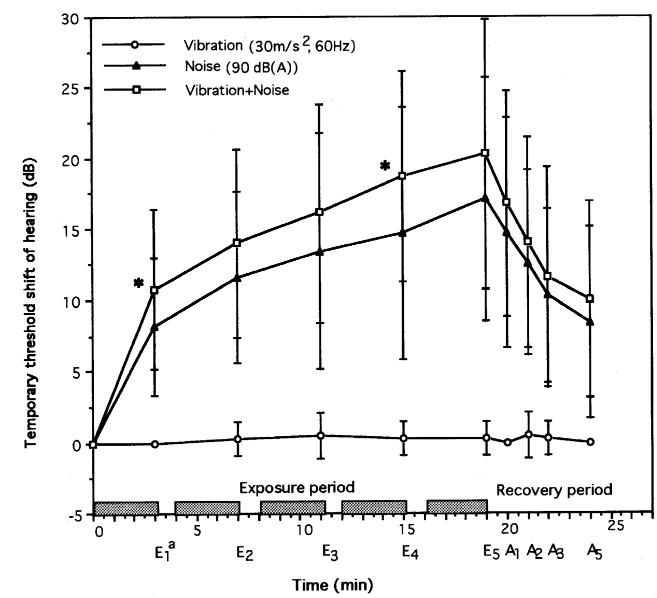

Fig. 3 TTS (dB) at 6 kHz during and after exposure to vibration (30 m/s^2, 60 Hz) and/or noise [90 dB(A)] (n = 19). *a* E_1 to E_5 represent TTSs measured in pauses after the first to the fifth 3-min exposures, and A_1 to A_5 represent TTSs measured at 1, 2, 3, and 5 min after fifth exposure. $*P < 0.05$, statistical difference by Wilcoxon matched-pairs signed rank test between noise exposure and combined exposure

At 4 kHz, almost no changes in TTSs were found from vibration exposure (Fig. 2). However, noise exposure and combined exposure caused significant increase in TTSs up to the fifth exposure and a decrease after cessation of exposure. When comparison is made between combined exposure and noise exposure, TTSs from combined exposure were significantly larger than those from noise exposure in each pause and 1 min after the cessation of exposure ($P < 0.05$ or 0.01), and the difference in TTS between them was 3.5 dB on average after the fifth exposure.

TTSs at 6 kHz showed results very similar to those at 4 kHz (Fig. 3): almost no changes from vibration exposure, and significant increases from noise exposure or combined exposure. TTSs from combined exposure were greater than TTSs from noise exposure, which showed significant differences between them at the first and fourth exposures ($P < 0.05$). The difference in TTS between noise exposure and combined exposure was 3.2 dB after the fifth exposure.

Discussion

The present study revealed that exposure to hand-arm vibration showed no significant increase in hearing threshold at any frequencies tested, while exposure to noise and a combination of vibration and noise caused a significant increase in TTSs, and simultaneous exposure to vibration and noise produced significantly greater TTSs at 4 and 6 kHz than exposure to noise alone. Thus, the present findings demonstrate the combined effects of hand-arm vibration and noise on hearing, though exposure to vibration alone did not affect the subjects' hearing under the conditions of the present experiments.

Concerning the combined effects of vibration and noise on hearing, there are several human experiments on whole-body vibration and noise (Yokoyama et al. 1974; Manninen 1983, 1984, 1986). These experiments have shown that whole-body vibration alone does not affect hearing, but a combination of whole-body vibration and noise causes combined effects on hearing. These findings are similar to the present ones in spite of the difference in kind of vibration; i.e., whole-body or hand-arm vibration. Conversely, there is only one recent experimental study of the combined effects of hand-arm vibration and noise on hearing. Although the previous study failed to show the combined effects clearly, TTSs of hearing tended to be greater in the combined exposure than in noise exposure at 4 and 6 kHz hearing level (Miyakita et al. 1987b). In the experiment, subjects were exposed to hand-arm vibration and noise by operating a chain-saw, which might complicate the experimental conditions and thus contribute to its failure. The present experiment clearly demonstrated the combined effects of hand-arm vibration and noise on hearing at 4 and 6 kHz.

With reference to the mechanisms of noise-induced TTS of hearing, three mechanisms have been generally considered: mechanical damage of the organ of Corti caused by excessive vibration of the basilar membrane, metabolic exhaustion of the hair cells (Lim and Dunn 1979; Lim 1986) and reduction of cochlear blood flow (Vertes and Axelsson 1981; Dengerink et al. 1984; Axelsson and Dengerink 1987; Thorne and Nuttall 1987). Recent studies measuring cochlear blood flow have revealed the importance of cochlear blood supply in noise-induced hearing loss. They have indicated that cochlear blood flow is reduced significantly more in noise-induced hearing loss than in normal hearing (Dengerink et al. 1984; Axelsson and Dengerink 1987; Thorne and Nuttall 1987). Moreover, noise exposure induces vasoconstriction of cochlear vessels and reduction of blood flow (Thorne and Nuttall 1987), and the sympathetic nervous system innervating the cochlear vessels plays a role in the reduction of cochlear blood flow and subsequently the development of noise-induced hearing loss (Honrubia and Goodhill 1979; Borg 1982; Durrant and Lovrinic 1984; Hildesheimer et al. 1991).

Since simultaneous exposure to hand-arm vibration and noise is shown to activate the sympathetic nervous system more than exposure to noise or vibration separately (Miyakita et al. 1987b; Sakakibara et al. 1989; Okada et al. 1991; Harada et al. 1993), greater TTS of hearing from combined exposure may be associated with a reduction of cochlear blood supply: higher sympathetic activities caused by combined exposure may produce stronger vasoconstriction in cochlear vessels and greater reduction of cochlear blood flow, and eventually lead to greater TTSs of hearing. However, exposure to vibration alone also activates sympathetic activity, though not as much as combined exposure (Sakakibara et al. 1990; Okada et al. 1991; Harada et al. 1993). Nevertheless, in the present study, exposure to vibration alone produced little TTS of hearing. It is, therefore, considered that noise exposure is essential to produce an increase in TTS of hearing and, together with noise exposure, hand-arm vibration can enhance the effect of noise on hearing by producing a higher sympathetic activity which might cause greater vasoconstriction in the inner ear.

The differences in TTS between simultaneous exposure and noise exposure were about 3.5 dB and 3.2 dB on average at 4 and 6 kHz after the fifth exposure in the present study, and the largest was 10 dB. Although the relationship between NIPTS and TTS of hearing is still obscure, the present experiment suggests that workers who are exposed to both hand-arm vibration and noise would have greater TTS of hearing on the job, which might result in greater NIPTS after prolonged exposure to vibration and noise. In the present study, subjects were exposed to hand-arm vibration of 30 m/s^2 at 60 Hz and/or noise of 90 dB for 15 min in all. More experiments under various exposure conditions are required to evaluate the risks of their combined effects on hearing.

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