Evaluation of Auditory Fatigue in Combined Noise, Heat and Workload Exposure

Chiou-Jong CHEN1, Yu-Tung DAI2, Yih-Min SUN2, Yi-Chang LIN3 and Yow-Jer JUANG2, 4*

1 Institute of Occupational Safety and Health, Council of Labor Affairs, Executive Yuan, Taiwan
2 Department of Occupational Safety and Health, College of Human Science and Technology, Chung Hwa University of Medical Technology, 89, Wen-Hwa 1st St., Jen-Te Hsiang, Tainan Hsien, Taiwan
3 General Education Center, Toko University, Taiwan
4 Institute of Environmental Health, College of Public Health, National Taiwan University, Taiwan

Received March 27, 2006 and accepted April 25, 2007

Abstract: This study was performed in a climatic chamber to evaluate the combined effects of noise intensity, heat stress, workload, and exposure duration on both noise-induced temporary threshold shift (TTS) and the recovery time by adopting Taguch’s method. Fourteen subjects without previous significant noise exposure and smoking history were recruited to participate in this study. All hearing threshold levels at eight different frequencies (250 to 8,000 Hz) of better ear were measured in an audiometric booth by using the ascending method in 2 dB steps before each exposure condition. The test was also carried out after exposure to evaluate TTS at various times. The TTS recovery time was assessed using an audiometric test on all subjects at post-exposure times of 2, 20, 40, 60, 80 and 120 min, respectively. It was found that TTS depended mainly on the exposed noise dose and was enhanced by workload and heat stress. The TTS recovery time is dependent upon the magnitude of the initial hearing loss. In conclusion, TTS driven by noise exposure is enhanced by heat and workload. Further studies are required to evaluate the effects of workload with extreme temperature in a workplace environment.

Key words: Noise-induced temporary threshold shift, Taguchi’s method, Heat stress, Workload, Combined effects, Recovery time

Introduction

Exposure to excessive noise is commonly encountered in a great variety of industrial processes and daily leisure activities. Present knowledge of the effects on the auditory system caused by noise exposure is based primarily on laboratory studies of animals and occupational studies on human beings. People may experience a measurable loss in auditory sensitivity when remaining in a noisy area, but will recover some time after returning to a quiet environment. This phenomenon can be measured as a shift in audiometric thresholds, and is called a noise-induced temporary threshold shift (TTS), or auditory fatigue.

Several studies have been conducted to investigate the effects of noise exposure patterns including noises of different spectra, interrupted noise exposure patterns, and short-duration noise exposures on TTS. From previous studies, a temporary decrease in auditory sensitivity in a normal ear was found after exposure to continuous noise levels above 80 dBA for long periods of time. Laboratory studies regarding the human response from noise exposure provide a better control over noise exposure variables, because TTS, which can be studied under controlled conditions in the laboratory, behaves fairly consistently. It is a relatively simple matter to determine combinations of levels, duration, and temporal pattern that produce the same TTS as the standard...
daily noise dose. However, low levels of TTS were induced due to the limitation of short exposure time and ethical reasons. Therefore, the human exposure to noise level is always less than the threshold of pain. Recovery from TTS after exposure cessation to noise depends on the severity of the hearing shift, individual susceptibility, and the type of exposure\(^9\). If recovery is not complete before the next noise exposure, there is a possibility that some of the loss will become permanent. As the initial threshold shift exceeds 35–45 dB after either continuous exposure to noise for about 12 h or intermittent exposures for long duration, the recovery from TTS appears to be very slow\(^{10}\).

In past decades, the interaction between noise and industrial chemicals or drugs has been studied and published in the literature\(^{11–17}\). Some studies proposed that synergism was only found in noise intensity above the critical level. Smoking was also found to be associated with increased odds of having high frequency hearing loss in steel factory workers\(^{18}\). The interaction of ototoxic chemicals (such as toluene, styrene, carbon disulfide etc.) and noise is more likely to affect individuals in the work environment\(^{19}\).

Moreover, the combined effects of noise and vibration on human performance and hearing loss have been studied for a long time\(^{20–23}\). The harmful effects of noise on auditory function can be altered significantly by exposure to additional factors that may or may not by themselves be ototoxic. When physical exercise and noise interact simultaneously, the TTS was reported to be greater than the exposure to noise alone\(^{24, 25}\). However, some studies demonstrated that workload does not increase TTS\(^{26, 27}\). As to the heat stress effect on hearing ability, it has been proposed in the previous studies that threshold shifts are not observed when exposed to heat stress only. But the hearing threshold of exposure to both heat and noise were obviously much higher those who exposed to noise only. Therefore, it was concluded that hearing loss can be enhanced by the combined effect of both heat and noise exposure\(^{28–35}\).

Taguchi’s method was developed in the 1980s by adopting traditional statistical modeling in combination with engineering concepts, to determine the degree of effect caused by control parameters and response analysis\(^{36}\). The most significant advantage of this method is its simplicity in the number of experiments conducted, especially under multiple factors. A statistical parameter, signal-to-noise (S/N) ratio, is derived to identify the main factor and study the variation in response. There are three formulae for the S/N ratio: (1) the-larger-the-better, (2) the-smaller-the-better, and (3) the-closer-the-better. A larger value of S/N ratio indicated a superior combination and considered preferable in this work, since the major signal dominated the noise.

In fact, most workplace environments consist of a myriad of physical and chemical agents that are potentially hazardous to health. Workers in a steel factory, for example, are subjected to combined exposure to heat stress and noise with a heavy workload. Except for vibration, the interaction between the combined effect of noise intensity, workload, exposure duration and heat stress on hearing still remains unknown. If a factorial design was adopted to study the combined effects of the above factors, many experiments would be required, while the main effect and interaction between these variables could not be clearly described. The purpose of this paper is to study the hearing threshold shift due to a combination of several factors such as heat stress, workload, noise intensity and exposure duration by adopting Taguchi’s method.

### Materials and Methods

#### Subject selection

Fourteen students (8 males; 6 females; aged 21.8 ± 1.4 yr) volunteered to participate in this study. All students, without previous significant noise exposure and smoking history were subjected to a medical examination. Their audiograms indicated no hearing impairments or acoustic trauma. Prior to the experiment, all subjects were informed of the risk associated with the study and signed a statement of informed consent. They were also asked to avoid medication, smoking, taking irritant foods, staying up late and being exposed to noise before the experiment. The physical characteristics of these subjects are shown in Table 1.

#### Simulation of exposure environment

A digitally controlled thermal exposure chamber with evaluated efficacy\(^{37}\) was used to simulate the heat stress. All driving units were adjustable using an automatic feedback control system to simulate air temperature (\(T_a\), relative humidity (RH), globe temperature (\(T_g\)), and air velocity (\(V_a\)), respectively, for the determination of specified wet bulb globe temperature (WBGT).

The noise generated by fans was recorded using a digital recorder (KALPA e:TALK Digital Voice Recorder, Taiwan) and stored in the LabView program for Windows to simulate steady-state noise. The signal was amplified and transduced using a loudspeaker for different noise intensities. The frequency spectrum of the simulated noise was analyzed using the Cirrus 800 series (CR:822A, Type 1, UK) and shown in Fig. 1. The maximum sound pressure level of the
simulated broadband noise was found at about 2,000 Hz.

Prior to the experiment, maximum work capacity (VO₂max) was measured on a treadmill ergometer (Track Master TMX425CP, USA) using the “Brook Protocol”. The theoretical maximum value (VO₂max) was then calculated from the measurement of oxygen consumption (VO₂max) and heart rate by MetaMax3B (Cortex, Germany) for all subjects while exercising on a treadmill ergometer at different speeds. The values of VO₂max were shown in Table 1. The test was stopped if the subjects were exhausted or heart rates were found over 200 beats/min. Based on each VO₂max of study subjects, it was possible to establish the workload settings required for each subject to achieve 10% (sitting on chair), 30% and 60% of VO₂max for the simulation of different workloads during the experiment.

Taguchi’s method

To investigate the effect of heat stress, workload, noise intensity and exposure duration on the hearing threshold and integrate the analysis results, an experimental design was required. To address this need for integration of all factors, Taguchi’s parameter design is proposed in this study as a framework for the experimental design.

Four controllable variables were selected in this study. There were three levels for each variable. These variables and their three levels were:

(1) heat stress of the environment (WBGT): 22°C (W1), 27°C (W2) and 32°C (W3);
(2) workload (% VO₂max): 10% VO₂max (M1), 30% VO₂max (M2) and 60% VO₂max (M3);
(3) exposure duration (time): 20 min (T1), 40 min (T2) and 60 min (T3);
(4) noise intensity (A-weighting equivalent sound pressure level; L_Aeq): 75 dBA (L1), 85 dBA (L2) and 95 dBA (L3);

The range for the three levels assigned to each of these variables was intended to simulate the range of exposed physical hazard in the workplace. A Taguchi’s L9 orthogonal array, shown in Table 2, was used to generate nine combined experimental conditions in this study. Therefore, all subjects were examined under nine conditions randomly on different days.

Experimental procedure and audiometric measurement

The experimental procedure for this study is shown in Fig. 2. Before each specified experimental condition was conducted, an audiometric baseline hearing threshold test (BHT) was performed on each subject 30 min after arrival. Tests were carried out in an audiometric booth that met the background noise requirements for ANSI S3.1-1999. The background noise level in the sound-insulated booth was 33.8 ± 1.5 dB during the test period.

A Beltone 2000 audiometer (USA) that had been calibrated in accordance with the ANSI S3.6-1996 recommendation was used for the auditory sensitivity measurements. The pure tone audiogram (PTA) test used the ascending method in 2 dB steps proceeding from 1,000 Hz to lower frequencies (500 and 250 Hz), and then back to 1,000 Hz and up to higher frequencies (2,000, 3,000, 4,000, 6,000, 8,000 Hz). The subjects were asked to listen carefully for successive pure tones and respond when they heard the tone. The test was repeated if two measurements at 1,000 Hz yielded a discrepancy greater than 5 dB. The lowest level at which two of the three given signals were identified was considered to be the hearing threshold level. The baseline audiometric measurements (L250, L500, L1,000, L2,000, L3,000, L4,000, L6,000, L8,000) were made before noise exposure at the following frequencies: 250, 500, 1,000, 2,000, 3,000, 4,000, 6,000 and 8,000 Hz. The weighted baseline hearing threshold level (HTL_BHT_weighted) of all pure tone frequencies for the better ear was determined by the following equation:

$$HTL_{BHT\_weighted} = 10 \times \log(10^{0.1 \times L_{250}} + 10^{0.1 \times L_{500}} + 10^{0.1 \times L_{1,000}} + 10^{0.1 \times L_{2,000}} + 10^{0.1 \times L_{3,000}} + 10^{0.1 \times L_{4,000}} + 10^{0.1 \times L_{6,000}} + 10^{0.1 \times L_{8,000}}).$$

The subject was then asked to wait in a quiet environment (dry bulb temperature in the range of 25 to 27°C) for noise level less than 55 dB followed by the experiment of each specified condition conducted in the thermal exposure chamber. The TTS recovery time was again performed using...
an audiometric test on all subjects at post-exposure times of 2, 20, 40, 60, 80 and 120 min. The weighted hearing threshold levels of post-exposure at different time points (HTL<sub>time_weighted</sub>) in this study were obtained using the following equation:

\[ HTL_{\text{time_weighted}} = 10 \times \log\left(100.1 \times L_{250} + 100.1 \times L_{500} + 100.1 \times L_{1000} + 100.1 \times L_{2000} + 100.1 \times L_{3000} + 100.1 \times L_{4000} + 100.1 \times L_{5000} + 100.1 \times L_{6000} + 100.1 \times L_{8000}\right). \]

**Data analysis**

All the data were analyzed and proceed by SigamaPlot for Windows (SPSS inc. 2001, USA).

**Results**

All of the subjects had normal hearing before exposure to different noise intensities in each experimental condition. The baseline hearing threshold level (BHT) averages of both ears for all subjects are shown in Fig. 3. The figure shows that better auditory sensitivity occurred between 3,000 Hz and 4,000 Hz for both ears, and no significant difference was found for BHT before each experimental condition.

To evaluate the existence of an interaction among noise intensity, heat stress and workload, we adopted Taguchi’s method by adding the exposure duration. The hearing loss coefficient (yi) in this study was defined as the ratio of weighted hearing threshold level at two minutes after exposure (HTL<sub>2_weighted</sub>) and weighted baseline hearing threshold level (HTL<sub>BH_weighted</sub>). The equation is expressed in the following:

\[ yi = \frac{HTL_{2_weighted}}{HTL_{BH_weighted}}. \]

According to the-larger-the-better characteristic, the S/N ratios were computed for each of nine experimental conditions using the formula: S/N = –10 × log(σ<sup>2</sup>),

where \( \sigma^2 = \sum 1/y_i^2 \). Therefore, S/N ratio of hearing loss coefficients were calculated from each test and shown in Table 3. Figure 4 is the response graph used to investigate the combined effects of four factors based on the result in Table 3. The above results (Table 3 and Fig. 4) were used to interpret the interaction between controlled heat stress, workload, and exposure duration and noise intensity on temporary threshold shift (TTS). It was found that the most serious effect on TTS was caused by the combination of W1, M3, T3, L3 (22°C, 60% VO<sub>2max</sub>, 60 min, 95 dBA). From Fig. 4, we can also find that noise intensity was the main factor affecting TTS among the four factors, followed by workload, exposure duration and heat stress. Exposure to noise levels at 95 dBA with heavy workload lead to significant TTS.

| Table 1. Physical characteristics of subjects in this study |
| Age (yr) | Height (cm) | Weight (kg) | VO<sub>2max</sub> (ml/kg/min) |
| Female (n=6) | 21.8 ± 1.5 | 160.5 ± 2.7 | 51.4 ± 4.2 | 38.0 ± 5.4 |
| Male (n=8) | 21.8 ± 1.5 | 169.5 ± 2.8 | 58.1 ± 7.3 | 38.9 ± 1.0 |
| All (n=14) | 21.8 ± 1.4 | 165.6 ± 5.3 | 55.2 ± 6.9 | 38.5 ± 3.5 |

<p>| Table 2. A Taguchi’s L₉ orthogonal array based upon the controlled variables and their three levels |</p>
<table>
<thead>
<tr>
<th>Experimental Conditions</th>
<th>WBGT (°C)</th>
<th>Workload (% VO&lt;sub&gt;2max&lt;/sub&gt;)</th>
<th>Exposure duration (min)</th>
<th>Noise intensity (dBA)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>22 (W1)</td>
<td>10 (M1)</td>
<td>20 (T1)</td>
<td>75 (L1)</td>
</tr>
<tr>
<td>2</td>
<td>22 (W1)</td>
<td>30 (M2)</td>
<td>40 (T2)</td>
<td>85 (L2)</td>
</tr>
<tr>
<td>3</td>
<td>22 (W1)</td>
<td>60 (M3)</td>
<td>60 (T3)</td>
<td>95 (L3)</td>
</tr>
<tr>
<td>4</td>
<td>27 (W2)</td>
<td>10 (M1)</td>
<td>40 (T2)</td>
<td>95 (L3)</td>
</tr>
<tr>
<td>5</td>
<td>27 (W2)</td>
<td>30 (M2)</td>
<td>60 (T3)</td>
<td>75 (L1)</td>
</tr>
<tr>
<td>6</td>
<td>27 (W2)</td>
<td>60 (M3)</td>
<td>20 (T1)</td>
<td>85 (L2)</td>
</tr>
<tr>
<td>7</td>
<td>32 (W3)</td>
<td>10 (M1)</td>
<td>60 (T3)</td>
<td>85 (L2)</td>
</tr>
<tr>
<td>8</td>
<td>32 (W3)</td>
<td>30 (M2)</td>
<td>20 (T1)</td>
<td>95 (L3)</td>
</tr>
<tr>
<td>9</td>
<td>32 (W3)</td>
<td>60 (M3)</td>
<td>40 (T2)</td>
<td>75 (L1)</td>
</tr>
</tbody>
</table>

WBGT: 22, 27 and 32°C; workload: 10, 30 and 60% VO<sub>2max</sub>; exposure duration: 20, 40 and 60 min; noise intensity: 75, 85 and 95 dBA.
The temporary threshold shift after 2 min exposure ($TTS_2$) to 95 dBA steady noise in three experimental conditions at different frequencies is shown in Fig. 5. The maximum $TTS_2$ centered on the 4,000 Hz pure tone when workload greater than 30% VO$_{2\text{max}}$. Therefore, $TTS$ for 4,000 Hz pure tone caused by exposure to 95 dBA noise during post exposure is investigated and shown in Fig. 6. It was found that the hearing threshold level will not return to baseline hearing threshold (BHT) within 120 min after exposure to 95 dBA noise at least 20 min. The $TTS$ recovery time is dependent upon the magnitude of the initial hearing loss. Workload was also found to be a dominant effect on the recovery time of $TTS$ induced by short-term exposure to intense noise, which agreed with the analysis by Taguchi’s method shown previously in this study.

Discussion

This study was conducted in a digitally controlled thermal exposure chamber to evaluate the combined effects of heat stress, workload, noise intensity and exposure duration on $TTS_2$ and the recovery time.

The simulated broadband noise was composed of octave bands centered around 2,000 Hz. $TTS$ caused by the noise with maximum energy concentrated in low-frequency components was found to be less than that concentrated in high-frequency components. Noises with energy concentrations between 2,000 and 6,000 Hz probably produce greater $TTS$ than noises concentrated elsewhere in the audible range$^{25,40}$. According to the previous review about $TTS$$^4$, the greatest $TTS$ was produced by noise shifts to 0.5–1 octave band above the frequency region of the test tones, in which the noise has its greatest concentration of energy. Based on the noise used (Fig. 1) in this study and result shown in Fig. 5, it was found that the greatest $TTS$ occurs at 4,000 Hz when workload greater than 30% VO$_{2\text{max}}$, which is similar to the finding from Miller$^{40}$. The significant $TTS_2$ were observed in the high frequency zone (3,000–4,000 Hz), which was also proposed in past studies$^{4,11}$. Noise frequency distribution spectrum was not considered in this study, however, it may interfere with the results. The effect of frequency distribution on $TTS_2$ needs to be investigated in further work.

From Fig. 4, it was observed that $TTS$ increases with workload, exposure duration and noise intensity. The significant increase was found especially for the noise intensity at 95 dBA (L3). In addition, it was found in Fig. 4 that exposure to noise at 95 dBA with simultaneous workload greater than 30% VO$_{2\text{max}}$ will also induce more $TTS$ than only noise exposure. The main factor of $TTS$ is noise intensity in this study. As to the effect of heat stress, the $TTS$ decreased when the heat stress was smaller than 27°C (W2) which is actually near the thermal comfort range for subjects at rest. However, the trend was inverted for heat stress greater than 27°C (W2).

From the field study conducted in glass bottle factory, high frequency hearing threshold was found to increase with
the duration when exposed to both heat stress and noise environment\textsuperscript{31}. A previous report stated that susceptibility to TTS is related to a person’s cardiovascular fitness. The hearing ability was improved after 8 weeks exercise training\textsuperscript{41}. The hearing loss caused by exposure to noise and heat simultaneously was higher than that exposure to noise only\textsuperscript{29–32, 35}. Therefore, it could be concluded that TTS will be enhanced by the combined effects of workload and heat stress when exposure to noise. However, the effect of noise exposure in the workplace with temperatures lower than 22°C on TTS still remains unknown and needs to be studied in future research.

Oxygen-dependent processes in the cochlea may be required for protection and/or repair of damage caused by severe noise exposure\textsuperscript{42}. Hair cells in the high-frequency region may rely on oxygen supply more than hair cells in the low-frequency region. The combination of increased metabolic demands during noise exposure and elevated blood temperature appears to interact unfavorably and deplete the reserve capacity of the cochlea, as evidenced by the demonstrated increase in TTS. The temporary changes of auditory sensitivity are caused by decrease in oxygen tension in the cochlear endolymph, and local vasoconstriction, especially of the stria vascularis\textsuperscript{43, 44}. For workers subject to heat stress, more skin blood flow is required to dissipate body heat, the decrement of cochlear blood flow is apparently expected. As a result, more TTS will be induced under combined exposure to heat stress and noise than exposure to noise only. Therefore, the mechanism

### Table 3. The S/N ratios of hearing loss coefficient (yi) calculated from 14 subjects at nine different experimental conditions

<table>
<thead>
<tr>
<th>Experimental Conditions</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\sigma^2$</td>
<td>15.15</td>
<td>13.81</td>
<td>6.22</td>
<td>10.97</td>
<td>16.61</td>
<td>14.94</td>
<td>14.64</td>
<td>10.01</td>
<td>13.31</td>
</tr>
</tbody>
</table>

$\sigma^2 = \sum 1/yi^2$, S/N = $-10 \times \log(\sigma^2)$

### Fig. 4. Response graph (S/N ratios) of four controlled variables at three levels.


### Fig. 5. The average temporary threshold shift 2 min after the end of the exposure (TTS\textsubscript{2}) in the frequencies ranging from 250 to 8,000 Hz at three different conditions.

### Fig. 6. Recovery from temporary threshold shift (TTS) at 4,000 Hz produced by exposure to 95 dBA of three different conditions in 14 ears.
to enhance the effect of noise by workload and heat may be
due to decrease in oxygen tension or blood flow in the cochlear
endolymph. Results of present study supported that noise
exposure in combination with workload and heat stress will
cause more TTS.

Hearing loss depends mainly on the intensity and exposure
duration after exposure to noise. The recovery time is
dependent upon the magnitude of the initial hearing loss.
Based on previous studies, the recovery time will be longer
if the initial hearing loss is greater. Note that by far the
greatest amount of recovery occurred during the first 15
minutes following the exposure. The recovery from the worse
condition in this study was observed still not complete at
the time point of 120 min after exposure. It is because the
recovery of TTS is not related simply to the magnitude of
the threshold shifts as was assumed in the development of
the damage risk contours (DRC) by Working Group 46 of
the NAS/NRC Committee on Hearing, Bioacoustics and
Biomechanics (CHABA).

Because TTS depends on noise intensity and the frequency
spectrum, the hearing loss due to continuous and steady noise
exposure was derived in this study based on the total
integrated level of acoustic energy over a given exposure
duration. Whether the findings obtained in this study will be
exactly the same as the results caused by the exposure to
interrupted and impulsive noise is still unclear. However,
the method developed in this paper to evaluate TTS could
be extended to account for the hearing loss from exposure
to intermittent and impulsive noise.

In conclusion, results of the present study indicated that
short-term intense noise exposure during heavy workload
in hot environments induced more TTS, especially at 95
dBA noise intensity. TTS increased with the duration of
exposure to both heat stress and noise environment during
heavy workload. The finding in this study supported that
TTS driven by steady-state noise exposure is enhanced by
heat stress and heavy workload. Heat stress and heavy
workload are the potential factors of increasing TTS for noise
exposure.

References

1) CHABA (1988) Committee on Hearing, Bioacoustics and
Biomechanics. Working group on speech understanding.
Speech understanding and aging. J Acoust Soc Am 83, 859–
95.
Williams & Wilkins, Baltimore.
noise spectra on auditory frequencies & degree of temporary
4) Kryter KD, Ward WD (1965) Hazardous exposure to
64.
5) Botsford JH (1967) Simple method for identifying acceptable
6) Ward WD (1970) Temporary threshold shift and damage-
risk criteria for intermittent noise exposures. J Acoust Soc
Am 48, 561–74.
Am 70, 390–6.
Geneva.
10) Ward WD (1960) Recovery from high values of temporary
simultaneous exposure to noise and toluene on hearing
function. Neurotoxicol and Teratol 19, 373–82.
alone or in concert with noise: a review of human studies.
In: Scientific Basis of Noise-Induced Hearing Loss, Axelsson
A, Hellstrom PA, Borchgrevink H, Henderson D, Hamernik
RP and Salvi RJ (Eds.), 437–46, Thieme Medical Publishers,
13) Mäkitie AA, Pirvola U, Pyykkö I, Sakakibara H, Rihimäki
V, Ylikoski J (2003) The ototoxic interaction of styrene and
exposure to noise and carbon disulfide on workers’ hearing.
Scand Audiol 18, 53–8.
15) Morata TC, Dunn DE, Kretschmer LK, Lemasters GL, Keith
RW (1993) Occupational exposure to organic solvents and
noise: effects on hearing. Scand J Work Environ Health 19,
245–54.
Evaluation of combined effect of organic solvents and noise
by the upper limit of hearing. Ind Health 38, 252–7.
of smoking and occupational exposure to noise on hearing
SP, Pavlas K, Starck J, Sulkowski W, Sinzuk-Walczak H
project on the effects of exposure to noise and industrial
chemicals on hearing and balance. Int J Occup Med Environ
Health 15, 5–11.
20) Grether WF, Harris CS, Mohr GC, Nixon CW, Ohlbaum M,
Sommer HC, Thaler VH, Veghte JH (1971) Effects of
combined heat, noise and vibration stress on human
performance and physiological functions. Aerospace Med


